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MarCoPola Polarimetric SAR Trial:

Signatures of Multiple Vessels with Aligned Operating Conditions

Chen Liu, Nicholas Sandirasegaram, Ryan A. English,
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Defence R&D Canada – Ottawa

TECHNICAL MEMORANDUM
DRDC Ottawa TM 2005-134
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Abstract

This memorandum addresses design, experimentation, and data collection components of the MarCoPola Polarimetric Signature trial that was conducted off the coast of Halifax, Nova Scotia, March 22-26, 2004 in conjunction with the CFAV *Quest* trial Q-281. Four ships participated as maritime targets in the experiments: *Quest*, CCGS *Sir Wilfred Grenfell* and CCGC *Sambro*, and *Divecom III*. C-band Synthetic Aperture Radar imagery of these targets was collected using the sensor on Environment Canada's CV-580 platform, with a supporting ENVISAT acquisition.

A radar calibration site was established at CFB Shearwater, which offered an adequately high TCR environment. The calibration site was composed of four active radar calibrators (ARC), four corner reflectors (CR) and two GPS base stations. Additional ground truthing of targets of opportunity were acquired by a CP-140 through contact tracking and photographs.

Fourteen lines of airborne Polarimetric SAR images were successfully collected with the target vessels exhibiting various speeds, incidence angles, aspect angles, and environmental conditions. One line was collected coincident with the ENVISAT acquisition. Four PolSAR lines were collected containing the Shearwater calibration site, also containing urban environments of the greater Halifax area. Seven lines of MTI data were obtained containing the target vessels, and two lines in MTI mode were collected for calibration.

Résumé

Le présent résumé traite des aspects de la conception, de l'expérimentation et de la collecte de données de l'essai de signature polarimétrique MarCoPola, qui a été mené au large d'Halifax (Nouvelle-Écosse) du 22 au 26 mars 2004, conjointement avec l'essai Q-281 du NAFC *Quest*. Quatre navires ont servi de cibles maritimes dans les expériences : *Quest*, NGCC *Sir Wilfred Grenfell* et CGCC *Sambro*, ainsi que *Divecom III*. On a recueilli des images de ces cibles à l'aide du capteur radar transporté à bord du CV-580 d'Environnement Canada, complétées par l'acquisition d'images satellites à l'aide d'ENVISAT.

Un site d'étalonnage radar a été établi à la BFC Shearwater, un milieu qui permettait d'obtenir un rapport signal de cible-clutter suffisamment élevé. Le site d'étalonnage était constitué de quatre étalonneurs radar actifs (ARC), quatre réflecteurs à coin (CR) et deux stations de base GPS (système de positionnement mondial). Des données additionnelles de vérification de terrain relatives à des cibles inopinées dans les zones d'imagerie ont été recueillies par le CP-140 par poursuite de contact et prise de photographies.

On a recueilli avec succès des images sur 14 lignes pour différentes vitesses, différents angles d'incidence, différents angles d'aspect et diverses conditions environnementales des navires cibles. L'acquisition des images sur une des lignes coïncidait avec l'acquisition par ENVISAT. Quatre lignes du PolSAR, utilisées pour la collecte d'images, contenaient le site d'étalonnage Shearwater, ainsi que des environnements urbains de la région du Grand Halifax. On a obtenu sept lignes de collecte de données MTI comprenant les navires cibles, et des données ont été recueillies en mode MTI sur deux lignes pour fins d'étalonnage.

Executive summary

Capabilities to exploit data from the upcoming RADARSAT-2 synthetic aperture radar (SAR) sensor are being developed by DRDC Ottawa in support of the Canadian Forces, including D Space D's Polar Epsilon project. Algorithms to automate the characterization of ships at sea using RADARSAT-2's Polarimetric and moving target indicator (MTI) modes can be largely validated prior to the launch of the satellite by acquiring data using the C-band SAR flown on Environment Canada's CV-580.

Polarimetric signature studies on a single vessel, DRDC's CFAV *Quest,* have been initiated on previous data. To validate that the resulting signatures are characteristic of differences among vessels, rather than imaging geometry or environmental conditions, a new collection of data focussing on multiple vessels operating in tandem is required. To implement this, the *Quest* has been employed again, with the assistance of Canadian Coast Guard ships and rented vessels that can be directed to manoeuvre in formation. By focussing data acquisition on these well-known and instrumented vessels, high-quality ground-truth can be collected to augment the radar data.

During the March 22-26, 2004 MarCoPola trial, held off the coast of Halifax, Nova Scotia, fourteen lines of PolSAR imagery were collected of the *Quest,* CCG and rental vessels, including one that was synchronized with an ENVISAT pass. In addition, 7 lines of MMTI data were collected of the CCG vessels. CP-140 MPA supporting flights provided tracking and photographs as ground-truth for non-cooperating targets in the experimentation region.

A calibration site located at CFB Shearwater provided active radar calibrator (ARC) and corner reflector (CR) instrumentation necessary to calibrate the Polarimetric data. This site was imaged by four PolSAR passes and 2 MMTI passes, with the surrounding urban and harbour regions included in these acquisitions.

The resulting data set provides a unique, valuable asset toward enabling new maritime intelligence, surveillance and reconnaissance (ISR) capabilities. In particular, the collection of SAR imagery and MTI data containing vessels operating together, exhibiting the same activity and near-identical geometry, will provide a test bed for identifying and eliminating algorithms that discriminate targets in a data-set based on characteristics inherent to operating conditions rather than the target.

The collection of coincident SAR imagery of the vessels from both the CV-580 and ENVISAT sensors will allow for further validation of the CV-580 SAR in its use as a surrogate for a space-based sensor. Ancillary data from the ship-board instrumentation and the calibration site extends the understanding of the extent of parameter variation between images, while the CP-140 data offers potential identification of targets of opportunity and sources of false alarms.

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Sommaire

RDDC Ottawa développe actuellement des capacités d'exploitation des données du futur capteur du radar à synthèse d'ouverture (SAR) RADARSAT-2 à l'appui des Forces canadiennes, notamment dans le cadre du projet Polar Epsilon de la DD Espace. Des algorithmes servant à automatiser la caractérisation de navires en mer à l'aide du mode polarimétrique et du mode MTI (visualisation des cibles mobiles) de RADARSAT-2 peuvent être validés en grande partie avant le lancement du satellite par l'acquisition de données à l'aide du SAR en bande C transporté à bord du CV-580 d'Environnement Canada.

Des études de la signature polarimétrique d'un seul navire, le NAFC *Quest* de RDDC, ont été réalisées d'après des données antérieures. Afin de confirmer que les signatures obtenues sont caractéristiques des différences entre les navires, et non de la géométrie de visée ou des conditions ambiantes, il fallait effectuer une nouvelle collecte de données axée sur plusieurs bâtiments naviguant de conserve. Pour ce faire, on a de nouveau utilisé le *Quest*, avec l'aide de navires de la Garde côtière canadienne et de navires loués que l'on pouvait faire naviguer en formation. En axant l'acquisition de données sur ces navires bien connus et munis d'instruments, on peut recueillir des données de vérification de terrain de haute qualité en complément aux données radar.

Durant l'essai MarCoPola, mené au large d'Halifax (Nouvelle-Écosse) du 22 au 26 mars 2004, des données relatives au NAFC *Quest* et aux navires de la GCC ainsi qu'aux navires loués ont été recueillies sur quatorze lignes d'imagerie PolSAR, une de ces lignes étant synchronisée avec un passage d'ENVISAT. De plus, des données MMTI relatives aux navires de la GCC ont été recueillies sur sept lignes. Les vols de soutien de l'APATMAR CP-140 ont permis la poursuite et la prise de photographies pour l'acquisition de données de vérification de terrain relatives à des cibles non coopérantes dans la région d'expérimentation.

Un site d'étalonnage établi à la BFC Shearwater a fourni les instruments des étalonneurs radar actifs (ARC) et des réflecteurs à coin (CR) nécessaires pour étalonner les données polarimétriques. On a recueilli des images de ce site sur quatre passages PolSAR et deux passages MMTI, l'acquisition de données portant aussi sur les zones urbaines et portuaires environnantes.

Le jeu de données obtenu constitue une ressource unique et précieuse pour offrir de nouvelles capacités de renseignement, surveillance et reconnaissance (RSR) maritimes. Particulièrement, la collecte d'images SAR et de données MTI relatives à des navires manœuvrant ensemble, exécutant la même activité et caractérisés par un gabarit presque identique, fournira un banc d'essai pour identifier et éliminer les algorithmes qui, dans un jeu de données, discriminent les cibles à partir des caractéristiques propres aux conditions ambiantes plutôt que propres aux cibles.

La collecte simultanée d'images SAR des navires, à l'aide des capteurs radar à bord du CV-580 et d'ENVISAT, permettra une meilleure validation du SAR à bord du CV-580 utilisé comme substitut de capteur spatial. Les données auxiliaires provenant des instruments à bord des navires et du site d'étalonnage permettent de mieux comprendre l'ampleur des variations

des paramètres entre les images, alors que les données du CP-140 offrent la possibilité d’identifier les cibles inopinées et les sources de fausses alarmes.

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1. Introduction

The MarCoPola Polarimetric Signature trial was conducted off the coast of Halifax, Nova Scotia in conjunction with CFAV *Quest* trial Q-281.

The trial consisted of five experiments: Polarimetric Signature Collection of Vessels at Sea, Wake and Ocean Observation, Maritime Moving Target Indicator (MMTI), Sea-Truthed False Alarm Collections and Halifax Urban/Harbour collection. These experiments were performed from March 22 to March 26, 2004.

As the expected launch date of RADARSAT-2 approaches, capabilities to exploit polarimetric synthetic aperture radar (PolSAR) imagery have become increasingly important to potential end-users of this data. In particular, the Canadian Forces, led by D Space D, will use RADARSAT-2 imagery for monitoring Canada's vast expanses of territorial waters, as envisioned by Project Polar Epsilon. Ideally, these capabilities should be available as soon as RADARSAT-2 becomes operational. So, it is desirable for new algorithms to be developed and validated prior to the launch of RADARSAT-2, particularly for the characterization of ships at sea based upon their polarimetric signatures.

Using the C-band Polarimetric SAR test bed sensor flown on the Environment Canada (EC) Convair 580 (CV-580) aircraft, many aspects of the expected radar performance of RADARSAT-2 may be investigated. The PolSAR imagery of known, instrumented vessels serves as a valued data set in the development of algorithms for RADARSAT-2 data. Since ongoing efforts exist to generate accurate signature models of the *Quest* for a variety of sensors, use of this vessel as a target will add helpful ancillary data to such a data set.

For an initial investigation, the Quest-2003 trial [1] was held October 1 - 9, 2003 located 240 nm south of Halifax, Nova Scotia, and focused on collecting polarimetric SAR imagery of a single well-know target vessel, the *Quest*, for which extensive RF modeling has been performed [2]. This data has formed the basis for analysis and algorithm development for characterizing the polarimetric signature. The next step is to validate that algorithms differentiating between vessels are able to do so on the basis of features characteristic to the vessels, and not something inherent to the collection, such as imaging geometry, sea state, or vessel activity. The MarCoPola trial aims to achieve this by having multiple vessels operate in tandem, thereby exhibiting nearly identical parameters inherent to the collection.

All aspects of satellite imagery cannot be simulated through the use of an airborne sensor. Nor is there existing commercial satellite imagery (CSI) that can provide the complete spectrum of data that RADARSAT-2 will generate. However, certain aspects can be exercised from current spaceborne sensors. By combining such CSI with the airborne PolSAR, a more thorough analysis of characteristics relevant to RADARSAT-2 may be performed.

RADARSAT-2 will operate primarily in imaging modes, but will also have experimental moving target indicator (MTI) modes. Like the PolSAR, these modes are implemented in the EC CV-580 test-bed for experimental purposes. Several experiments for ground MTI (GMTI) have proven successful in providing developmental and validation data for algorithms dealing

with vehicles moving over land. Investigations into applications for MMTI have followed, but significantly more data is required to draw meaningful conclusions. The environment and vessel instrumentation requirements for PolSAR trials also provides an ideal opportunity to acquire such MMTI data, so these data collects are planned together whenever possible.

By collecting calibration imagery, i.e., imaging a land-based calibration site that consists of active and passive instruments, post-processing can derive parameters to enhance the analysis of the maritime target data. Positioning the calibration site in or near an urban area allows the simultaneous collection of urban-based data without expending any additional resources.

The data acquired of cooperating maritime targets typically covers an extensive area of ocean that may include significant targets of opportunity, such as non-cooperating vessels or even non-vessels, either natural or man-made. When automated detection algorithms are applied, both cooperating targets and targets of opportunity may be selected. Since higher-level algorithms, such as those for polarimetric signature analysis, require significantly more computing resources than detection algorithms, it is desirable to eliminate false-alarms from the detection list wherever possible. In order to validate false-alarm reduction algorithms, ground-truth about all targets in the detection list is a requirement. Thus, the collection of sea-truthing, identifying information about all targets that might appear in the maritime data collection, will be employed whenever its acquisition can be obtained without interfering with the PolSAR imagery or the experiment itself.

2. Experiment Design

The objectives of the MarCoPola Polarimetric Signature trial were set out as:

- To acquire maritime data, with various types of vessels (small to large) under a variety of conditions (including non-maneuvering and moving vessels);
- To collect sea-truthing within the imagery footprint, including both targets and false alarms;
- To acquire airborne SAR data coincident with RADARSAR-1 and/or ENVISAT passes; and
- To collect data of Halifax Urban/Harbor area to support the Earth Observation Application Development Program (EOADP).

The data sets to be acquired from the trial are important for determining the effect of ship velocity and motion on the ship polarimetric signature; for developing ship selection, ship wake detection, and ship classification algorithms, and for ship velocity estimation. These data are important to investigate the lower limits of vessel size that the PolSAR detection capability can support. The synchronization of data acquisitions for airborne and spaceborne SAR systems is important for evaluating the performance of ship detection algorithms developed using airborne SAR data for RADARSAR-2 applications. RADARSAT-2 will offer several modes, including polarimetric (i.e. HH, HV, VH, and VV).

A number of parameters need to be considered when designing a trial in which the number of SAR scenes that can be collected is limited. For example, the flight lines were selected to collect imagery of the vessels at various *incidence angles* and *aspect angles* for a range of *vessel velocities* and *environmental conditions* that complement previous PolSAR data collections. The CV-580 SAR sensor, originally developed by Canada Centre for Remote Sensing (CCRS), can be operated either in right or left looking mode [3,4]. By accepting imagery from either side, more flexibility is available in the flight plan, usually allowing for more lines per flight.

Participation of DRDC's research vessel, *Quest,* was a high priority for proceeding with the trial. *Quest* was already to be operating between St. Margaret's Bay and LeHavre Basin in accordance with Cruise Q-281. Availability of the *Quest* for MarCoPola purposes was limited to March 24, 2004 and during transits on the evenings of March 23 and 25, as indicated with shaded red in the trial schedule shown in Figure 1. During these periods, only two tie-in satellite passes were available, the 22:01 ENVISAT pass on March 23, and the 18:00 RADARSAT pass on March 25. Therefore, these became the primary and contingency schedules, respectively, for the airborne/spaceborne tie-in component of the trial. A further requirement to provide the CV-580 pilots a 12-hour recovery period between flights limited the scheduling of the primary PolSAR flight to the afternoon of March 24. Since the *Quest* was not required for the MMTI component of the trial, this flight and contingencies were scheduled around the others, maintaining the 12-hour recovery period requirement.

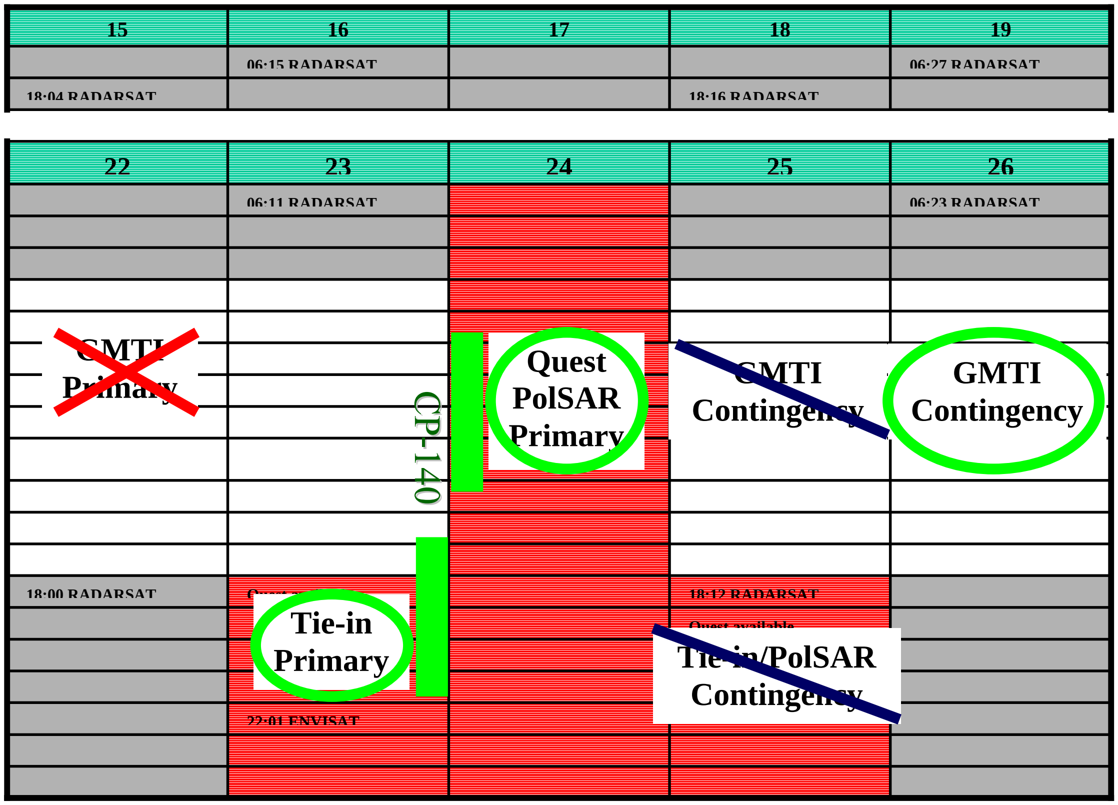

Figure 1: Trial schedule including approximate satellite overpass times (local time: EST) for March 15-26, 2004. The red X indicates that the MMTI Primary flight was cancelled. The green circles indicate successful airborne imagery acquisitions. Blue slashes indicate contingency slots not used. The green bars indicate times at which CP-140 support was provided.

Participating in the trial were *Quest,* CCGS *Sir Wilfred Grenfell*, CCGC *Sambro*, and the small fishing boat *Divecom III*. On March 23, the *Quest*, *Grenfell* and *Sambro* participated in the experiment. On March 24, the *Quest* was operating in a different location from CCG vessels, which forced the experiment to be divided into two parts. The *Grenfell*, *Sambro* and *Divecom III* were imaged in the 1st part and *Quest* was imaged in the 2nd part of the experiment. The dimensions of each vessel are indicated in Table 1.

To handle targets other than the cooperating vessels, CP-140 flights for sea-truthing were coordinated with the primary acquisition schedules, as shown by the green bars in Figure 1. Contact logs and photographic snapshots of all significant targets in the experimental region would be obtained. This degree of sea-truthing was expected to provide sufficient knowledge to validate false-alarm identification algorithms when applied to the SAR imagery.

The key parameters for the vessels and the aircraft participating in the trial are summarized in Table 2 for March 23 and Table 3 for March 24. In order to capture all participating vessels within the scene, the vessels' velocity and course relative to the aircraft heading, the

geometric imaging aspect angle, must be considered when planning each acquisition, especially for small incidence angles with high target velocity passes. Here, the geometric imaging aspect angle, abbreviated herein as the aspect angle, is defined as the aircraft/sensor heading relative to the target heading. When imagery collected using a right-looking configuration is represented as a matrix of pixels, the geometric imaging aspect angle then corresponds to the usual mathematical rotation angle for 2-dimensional Euclidean space.

Since the participating vessels will be separated in distance from each other, the incidence angle and aspect angle for each vessel location will often be different. To meet the requirement that the new data is complementary to existing data, maintaining consistency of the incidence angles and aspect angles for all vessels in each scene needs to be carefully considered. This could be accomplished by minimizing the distance between vessels, however, wake effects due to adjacent vessels must also be considered, which are undesirable. Balancing these planning constraints, the vessel tracks were arranged in a right-triangle configuration. Each day, the two larger vessels were offset by 1 nautical mile (nm) abreast, and the smaller vessel was offset from the lead large vessel by 2 nm astern, as illustrated in Figure 2 and Figure 3. The decision to place the smaller vessel astern of the larger one was taken since the smaller vessel had the speed and manoeuvrability to place itself back in appropriate position when the formation turned around (180°) for the next pass, in the opposite direction. A detailed calculation was performed for each ship to ensure that the designed parameters could approximately be achieved for each scene. For example, there was a concern for the 15 knots (kt) case that the larger vessels may not be able to keep up; detailed information is given in Annex E.

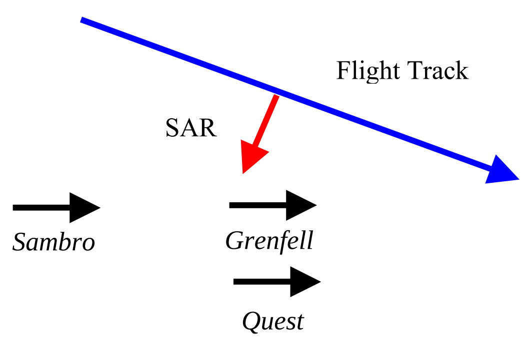

Figure 2: Example of March 23 vessels track.

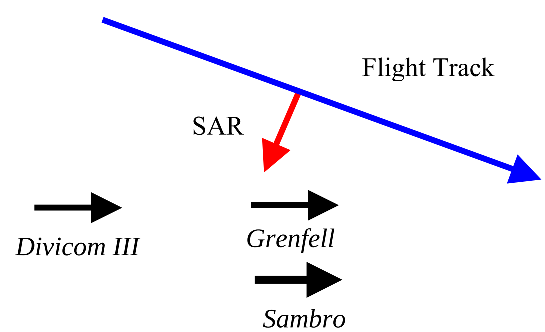

Figure 3: Example of March 24 vessels track.

Table 1: Vessel dimensions.

Name	Dimension (m)
CFAV *Quest*	76 x 12.6
CCGS *Sir Wilfred Grenfell*	68.48 x 15
CCGC *Sambro*	16.25 x 5.18
Divecom III	13.3 x 4.45

Based on the ENVISAT swath-planning information, there would be only one pass covering the experimental region during the trial, and so a simultaneous CV-580 SAR image acquisition was planned. To achieve a synchronized image acquisition between the CV-580 SAR and CSI, the target vessels needed to be located within the swaths of both sensors. For maximum flexibility, the experimental region was determined by intersecting the expected footprints of the most relevant CSI, as shown in Figure 4. The primary airborne/spaceborne tie-in collection was obtained in conjunction with the March 23 ENVISAT overpass. For this acquisition, the proposed parameters were to have the incidence angle at 45°, the vessels' speeds at 10 kt, and the aspect angle of 45° (i.e. imaging from port bow). When a target moves with an angle towards the sensor, it has motion in the along-track and cross-track directions. The target motion causes the image smearing in both range and azimuth directions, where the cross-track motion introduces the image shift in azimuth direction.

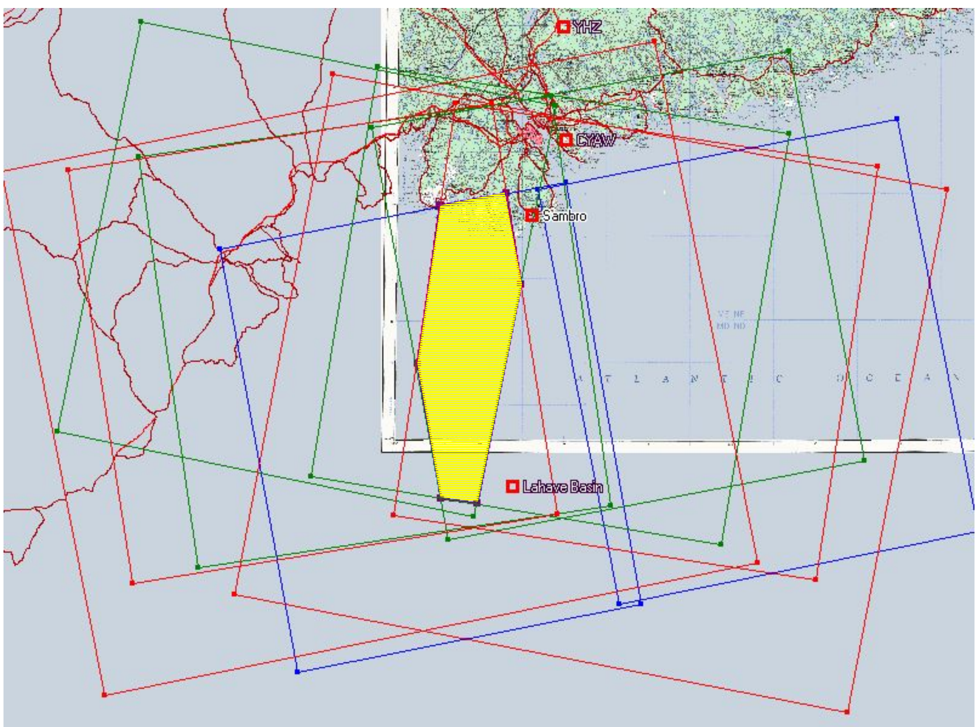

Figure 4: Expected footprints for CSI collections relevant to MarCoPola trial dates and locations. Yellow shaded area shows region of best overlap for image used to optimize target position planning.

For the PolSAR experiments, two flights were planned. Each flight was estimated to be four hours long based on the flight mission requirements. A detailed mission plan can be found in [5]. Each mission consisted of 8 flight lines over the vessels and 2 flight lines over the

calibration site, Halifax harbour and urban areas. No contingency flight lines were planned, as the full CV-580 dwell time was accounted for.

A good communication plan is critical for a successful trial, especially for a trial involving multiple moving targets. During the experiments, the aircraft needs to contact to vessels to give commands to have the vessels move according the plan and synchronizing with the SAR sensor operation during each image acquisition. The vessels also need to communicate to coordinate during the image acquisition. To achieve this, a leading vessel was appointed with the responsibility for communication with both aircraft and other vessels. The aircraft, as the mission lead, communicates instructions to the lead vessel, with all other vessels monitoring the communications during each image acquisition. The lead vessel also serves as the center target for the SAR mission plan. On March 23, the lead vessel was the *Quest*, while in the first part of the experiments on March 24, the lead vessel was the *Grenfell*. The aircraft pilot provided the communication plan as detailed in Annex C.

In order for other participating organizations to understand the trial requirements, a trial briefing was given at DRDC Atlantic by a member of the planning team. A concurrent video teleconference was held between DRDC Ottawa and DRDC Atlantic. The experiment plan and all requirements for each participant were presented during the briefing. For the trial, selected DRDC Ottawa trial team members would be assigned to each participating vessel, to brief the crew prior to the event and to be onboard during the trial. Since sea-truthing, as described above, was to be collected by CP-140, the trial requirements would also have to be relayed to 14 Wing Greenwood staff. The military liaison officer from DRDC Atlantic attending the briefing was available for this task; otherwise alternate means would have had to be arranged. 14 Wing Greenwood staff played an important role by supporting us with CP-140 Aurora and providing post-flight mission data retrieval.

During the radar passes, position, velocity and motion of each vessel should be recorded. *Quest* has 3-axis accelerometer on board to record such information. Other vessels did not have the same capacity. Therefore, a Trimble Global Positioning System (GPS) unit was operated by DRDC Ottawa staff on each vessel. It provided the vessel location information during imagery acquisition, enabling the corresponding vessel velocity to be estimated from the GPS data. Additional information related to weather, sea state and other events, was recorded to provide an understanding of phenomenology observed in the resulting imagery and its analysis.

Table 2: March 23 flight

	VESSEL INFORMATION				AIRCRAFT INFORMATION					
Line	Vessel Location	Vessel bearing	Vessel speed (kt)	Centre Target	Incident angle	Aircraft heading	SAW^{-1}	Flight pass time (min)	Flight positioning time (min)	Targets
Cal 1				Shearwater	45°	138°/Right	Off			Halifax harbor, Urban, Cal site
Cal 2				Shearwater	35°	318°/Left	Off			
L1	44^0 17′ N 63^0 45′ W	Stationary 270°	0	*Quest*	45°	45° to Quest	Off	5	20	*Quest, Sambro, Grenfell*
L2		270°	5	*Quest*	45°	45° to Quest	Off	5	20	
L3		90°	5	*Quest*	35°	45° to Quest	Off	5	20	
L4		270°	10	*Quest*	45°	45° to Quest	Off	5	20	
L5		90^0	10	*Quest*	35°	45° to Quest	Off	5	20	
L6		270°	5	*Quest*	45°	⊥ to Quest	Off	5	20	
L7		90°	5	*Quest*	35°	⊥ to Quest	Off	5	20	
L8		270°	15	*Quest*	45°	// to Quest	Off	5	20	

Table 3: March 24 flight

	VESSEL INFORMATION				AIRCRAFT INFORMATION					
Line	Vessel Location	Vessel bearing	Vessel speed (kt)	Centre Target	Incident angle	A/C heading	SAW^{-1}	Flight pass time (min)	Flight positioning time (min)	Targets
1	44^0 18′ N 63^0 45′ W	Stationary 270°	0	CCG large vessel	45°	// to CCG large vessel	Off	5	20	*Grenfell, Sambro, Divecom III*
2		270°	5	CCG	45°	45° to vessel	Off	5	20	
3		90°	5	CCG	35°	45° to vessel	Off	5	20	
4		270°	10	CCG	45°	45° to vessel	Off	5	20	
5		90°	10	CCG	35°	45° to vessel	Off	5	20	
CV580 Moves South										
6	43^0 54.0′ N, 63^0 39.0′ W	270°	5	*Quest*	45°	45° to Quest	Off	5	20	*Quest*
7		90°	5	*Quest*	35°	45° to Quest	Off	5	20	
8		270°	10	*Quest*	45°	135° to Quest	Off	5	20	
Cal 1				Shearwater	45°	138°/Right	Off			Halifax harbor, Urban, Cal site
Cal 2				Shearwater	35°	318°/Left	Off			

3. Calibration Site and Calibrators

The radar sensor employed during this trial, an airborne C-band SAR, was used to collect strip-map polarimetric SAR data. This radar sensor was originally developed by CCRS and is now operated by EC onboard the CV-580 aircraft [4]. The slant range resolution is 5.7 m and in the azimuth resolution is 0.85 m [4]. Polarimetric calibration is an essential requirement for the CV-580 radar system. The calibration is accomplished on the basis of the backscattered magnitude and phase information of the four channels. Therefore, it is necessary to measure the phase relationship and absolute values of the amplitude from each channel in order to achieve calibration of the system. This can be done with the help of external calibration using known calibrators, such as Active Radar Calibrators (ARCs) and Corner Reflectors (CRs). The ARCs are used for calibrating phase response between each channel, while the CRs are used for absolute calibration for this radar. In addition to the ARCs and CRs, two GPS base stations (Ashtech Z12) were deployed at the calibration site to provide data for performing positional error correction for the CV-580. This position calibration using data obtained from two GPS station are referred as differential GPS (dGPS). The dGPS data improves the accuracy of the aircraft position.

3.1 Establishment of calibration site

There are several considerations in selecting the location for the calibration site. Notable concerns include:

- Unobstructed line of sight along signal path;
- Low, uniformly reflective surface and relatively “flat” to provide high target-to-clutter ratio (TCR);
- Sufficient separation distance between each calibrator to avoid the radar antenna side lobe effects. In general, the separation distance should be at least 10 times the resolution.

The selected location for the calibration site was “Taxiway West Delta” at 12 Wing/Canadian Forces Base (CFB) Shearwater, Halifax, Nova Scotia. Figure 5 shows the Runways and Taxiways, with West Delta highlighted in green. Figure 6 was obtained from GPS field survey data and indicates the location of the calibration devices. Four trihedral CRs and four ARCs were alternately deployed in a co-linear manner, about 60 m apart from each other, and facing NE for this trial. The CRs and ARCs were deployed onto the centre line of the West Delta taxiway to obtain the low and uniform clutter distribution surrounding the target. This will provide sufficient TCR. The overall deployment line was along a bearing of 318° T. Also, CRs were anchored using “dead men” to prevent the wind from blowing the units over.

Two GPS base station were also deployed. One was deployed over a known survey monument to perform positional error correction for the CV-580, and the second was deployed to provide redundancy for the trial’s critical data sets.

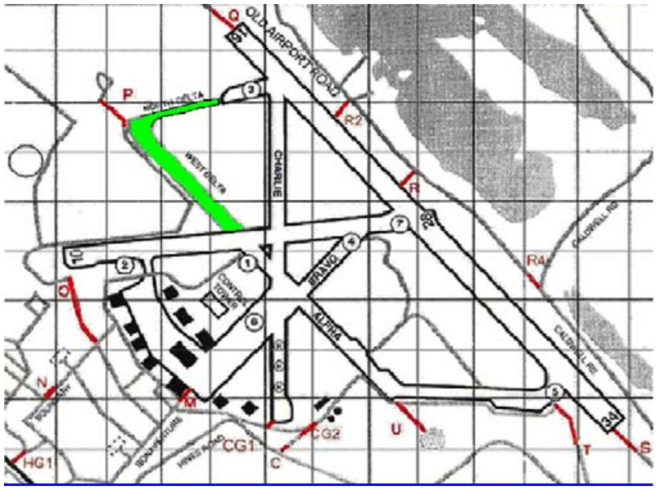

Figure 5: Sketch of CFB Shearwater Runways and Taxiways.

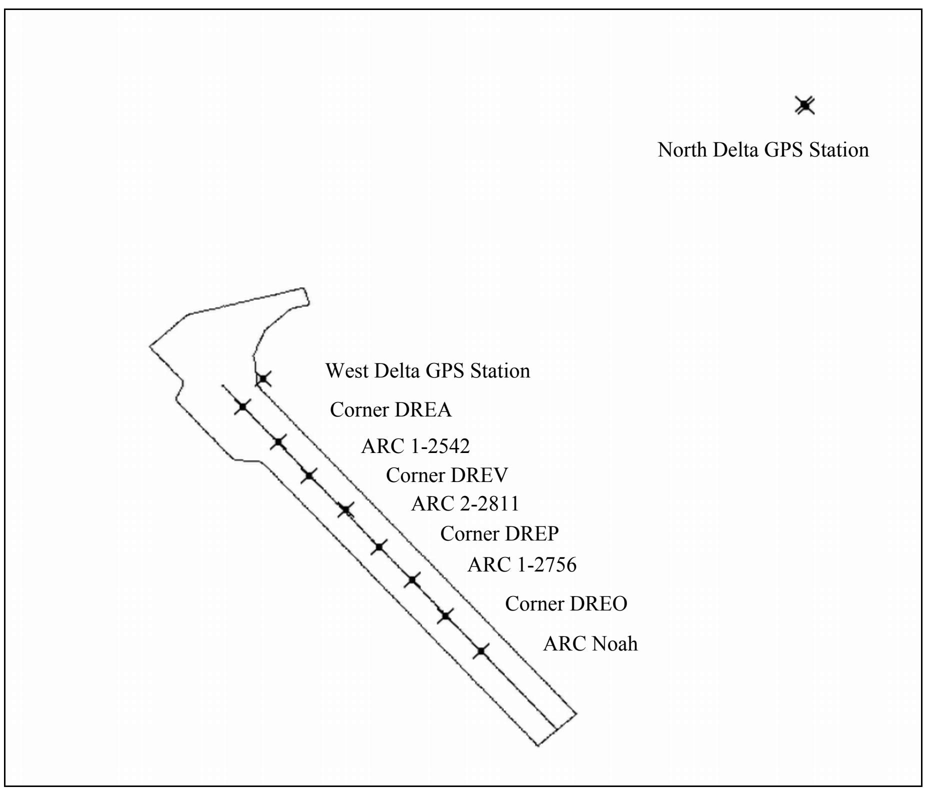

Figure 6: CFB Shearwater West Delta Calibration Site March 2004.

The actual geo-location of all ARCs, CRs and GPS stations are listed in Table 4. The GPS measurements were performed with a Trimble Pro XR DGPS beacon receiver. A Silva Model 530 Ranger Ultra magnetic compass was used to set the azimuth angle and a SMART Tool ½ foot electronic level was used to setup the elevation angle for the ARCs and CRs. The local magnetic declination applied for the Shearwater Base was 19.4° west.

Notably, there were two vehicles were parked on "Taxiway West Delta", near the calibration devices. The truck (manufactured by International) was located at N 44 38 26.1, W 63 30 21.6, and the car (PT Cruiser) was located at N 44 38 24.7, W 63 30 23.6.

Table 4: Geo-locations of calibrators

Waypoint #	Position	Latitude	Longitude	Altitude (m)	EHE
North Delta	GPS Antenna (BM 66D31)	N 44 38 51.06920	W 063 30 09.23370	42.344	0.8
West Delta	GPS Antenna	N 44 38 39.69599	W 063 30 38.10063	44.442	0.7
West Delta	CRN-DREA	N 44 38 38.54280	W 063 30 39.17557	44.875	0.6
West Delta	ARC 1-2542	N 44 38 37.07876	W 063 30 37.24303	44.062	0.7
West Delta	CRN-DREV	N 44 38 35.70067	W 063 30 35.62361	43.709	0.7
West Delta	ARC 2-2811	N 44 38 34.27651	W 063 30 33.67799	44.069	0.7
West Delta	CRN-DREP	N 44 38 32.75059	W 063 30 31.90426	43.090	0.8
West Delta	ARC 1-2756	N 44 38 31.38169	W 063 30 30.08363	43.317	0.8
West Delta	DREO	N 44 38 29.91548	W 063 30 28.33777	43.058	0.7
West Delta	ARC Noah	N 44 38 28.43342	W 063 30 26.43004	42.589	0.8

3.2 Corner reflectors

All trihedral CRs were setup to align the front horizontal edge of the CR with the flight line and the boresight of the CR aligned with the radar sensor to maximize the signal return. The boresight angle calculation is given in Annex A.

Usually elevation angle is considered in setting the CRs. The elevation angle (θ_{elv}) is measured from the horizontal plane (parallel to the ground) and the base surface of the CR as shown in Figure 7. Therefore, the elevation angle is measured as follows

$$\theta_{elv} = 90° - (\theta_{inc} + \theta_{bore}) \qquad (1)$$

where θ_{bore} is the inherent bore elevation of a CR from horizontal and θ_{inc} is the desired incidence angle.

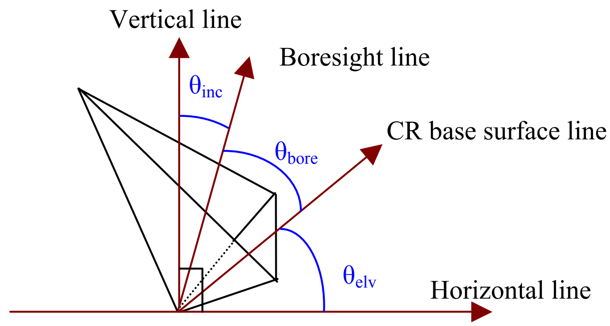

Figure 7: Relationship between elevation, bore-sight and incident angles.

The Radar Cross Section (RCS) of a trihedral CR is calculated using

$$\sigma = \frac{\pi \cdot h^4}{3 \cdot \lambda^2}, \tag{2}$$

as per the Quest trial technical memorandum [1] and reference [6]. Here, σ is RCS in m^2, *h* is the hypotenuse of the CR in meters and λ is wavelength of the radar signal in meters.

In this trial, corner reflectors referenced it as DREA, DREV, DREP and DREO were deployed. The length of the edge (or box) for each of these is 0.75 m. These CRs were individually mounted on Dutch Hill 1200, survey quality, electrically non-conducting tripods via custom made tripod heads. The tripod head, constructed of a non-ferrous aluminum alloy, allows the CR to be moved in both vertical and horizontal directions. Therefore, the CRs can be adjusted to the boresight for each flight line. An example of a CR setup is shown in Figure 8. The wooden "deadman" and sandbags, used to secure the CR against movement due to strong wind, can also be seen. Note that some of calibration devices were set on snow-covered ground.

Figure 8: Corner Reflectors Setup. a) Front view and b) back view.

3.3 Active radar calibrators

The ARC is an electronic apparatus. In the ARC circuit design, a receiver, amplifier and transmitter are included. The ARC receiver obtains the radar signal, the amplifier amplifies the signal then the transmitter sends the signal back to the radar sensor. The peak Radar Cross Section of ARC is given by [7,8]:

$$RCS = \frac{G_e \, G_R \, G_T \, \lambda^2}{4\pi} , \qquad (3)$$

where G_R and G_T are the horn receiving and transmitting antenna gains, respectively, G_e is the electronic gain, and λ is the wavelength of the radar signal.

In this trial, Active Radar Calibrators Power Hog (CCRS 1-2542), Serafina (CCRS 1-2756), Gemini (CCRS 2-2811) and Noah (DRDC Ottawa) were deployed on West Delta. Setup for all the ARCs are shown in Figure 9.

The signal from Gemini (CCRS 2-2811) was weak on 22nd of March 04 and was improved by replacing the faulty N-cable between the two boxes which forms the transmit and receive portions of the device.

For the Noah, the received signal and transmitted signal data can be saved as a data file. The received signal can be viewed in real time (Figure 10). Figure 11 shows an example with the recorded transmit (green) and receive (blue) radar signals on March 24 (21:26:43 UTC), 2004.

a)

b)

c)

d)

Figure 9: Active Radar Calibrators Setup.

a) Noah (DRDC Ottawa), b) Gemini (CCRS 2-2811), c) Serafina (CCRS 1-2756), and d) Power Hog (CCRS 1-2542)

Figure 10: The received signal in real time.

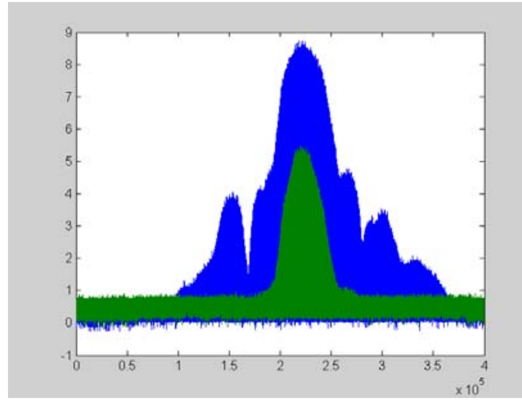

Figure 11: Received and transmitted Radar signals by Noah on March 24 (21:26:43 UTC).

3.4 GPS base station

In this trial, two Ashtech Z-12 GPS base stations were deployed at CFB Shearwater. One unit was set-up in the low grass at the north end of West Delta, while the other was established over the survey benchmark 66D31 on the east side of runway 16/34. The purpose of the deployment is to calculate the corrections necessary to obtain an exact aircraft position for processing of the collected radar data. The deployment of a GPS system is shown in Figure 12. The antenna height was measured with reference to the survey benchmark. The survey benchmark is shown in Figure 13.

Figure 12: GPS base station setup.

Survey Bench Mark Reference Data - North Delta
Unique Number: 661516
Name : PM 66 D 31
Established By : Mapping And Charting
Establishment - Nd
Province: NS
NTS Map No: 011D12
Latitude: N44° 38' 49”
Longitude: W63° 30' 11”
Agency Geodetic Survey Division – NRCan
Vertical Datum: CGVD28
Elevation: 41.160 m

Figure 13: Survey BM 66D31.

4. Polarimetric SAR Image Acquisition

The PolSAR data was obtained using the EC CV-580 airborne C-band SAR. The Nadir mode of the PolSAR sensor was used in the trial. This mode normally includes nadir, but was operated with a range gate delay (RGD) offset such that the swath footprint covers incidence angles from $\theta = 28°$ to $\theta = 74°$, with optimal center target location at an incidence angle of approximately 57°, providing an approximate swath width of 20 km, subject to terrain and altitude variation. The image coverage in the azimuth direction depends on the aircraft ground speed and the data acquisition time. The azimuth distance during each acquisition was selected to be 20 nm (i.e. about 37 km) in this trial. The nominal imaging geometry used during the MarCoPola trial is illustrated in Figure 14 [1,4].

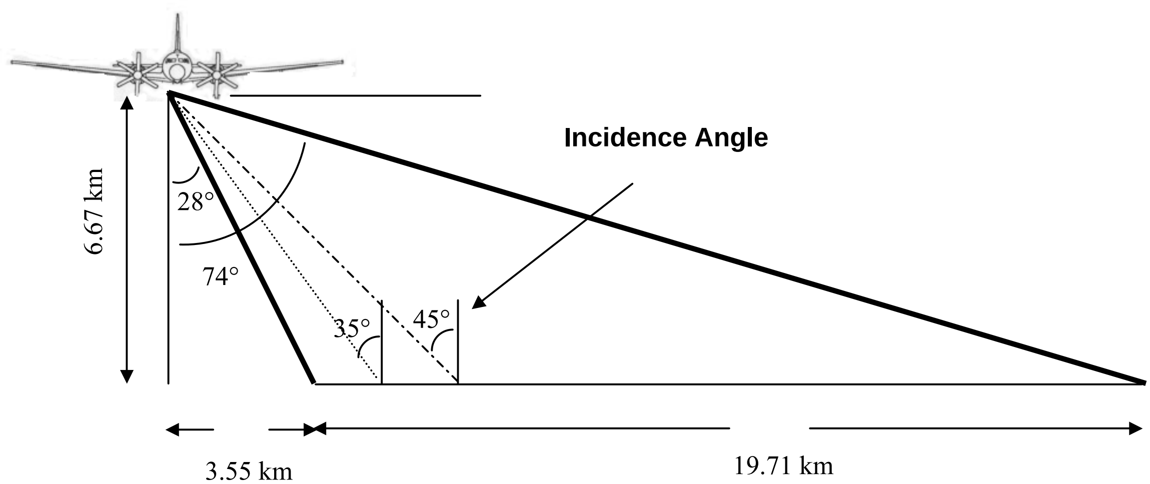

Figure 14: Geometry for the EC CV-580 PolSAR acquisition.

The C-band (5.30 GHz, λ=5.66 cm) SAR is a polarimetric system, providing four combinations of incident and scattered electric fields, HH, HV, VH, and VV. A polarimetric SAR system is often described mathematically by a 2×2 scattering matrix, *S*, with components S_{HH}, S_{HV}, S_{VH} and S_{VV}. An *S* matrix is measured for each sample element (i.e., pixel) in an image. The components of *S* can be written as [9]:

$$S = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \tag{6}$$

Since multiple vessels participated in the trial, the incidence and aspect angle for each image were defined using the lead vessel. The incidence and aspect angle were slightly different for each vessel in an image since the vessel tracks were arranged in a right-triangle configuration (see Figure 2 and Figure 3). The aircraft flew at a nominally constant altitude. To obtain a

designed incidence angle at the centre target (lead vessel), the aircraft was flown at various lateral offset distances from the image centre. The aspect angle used for each acquisition is defined by the difference of the aircraft bearing and the center target course. During the experiments, the radar receiver was operated with the Surface Acoustic Wave (SAW) compressor bypassed (SAW^{-1} Off configuration) to reduce point-target saturation problems of this radar [10,11] and sensor was operated in either right or left looking mode.

Throughout the experiments, the velocity of vessels remained constant during each image acquisition. However, different velocities were assigned for different flight lines. The first flight line for each day was assigned zero velocity, so the vessels were static with engines idle (see Table 2 and Table 3).

5. Initial Polarimetric SAR Results

5.1 General

A total of 16 acquisition lines of polarimetric imagery were successfully collected and processed, including 14 vessel images and 2 calibration site images.

DRDC Atlantic collected the *Quest* ground truthing information, including NADAS (Non-acoustic Data Acquisition System) data and ship motion data. NADAS data contains the speed over ground (SOG) and course over ground (COG) data in which wind effects are included, while ship motion and the wave information are obtained from ship motion data.

There was no equipment on other ships that could provide ship motion information, therefore, DRDC Ottawa scientists were deployed on each ship with a dGPS system to acquire the ship location during the trial. Using the dGPS data, it was also possible to estimate the velocity of each vessel.

The key operational parameters of the aircraft and the vessels during the trial are summarized in Table 5 to Table 7. The detailed environmental data extraction can be found in [12], and the collected information during the data processing is summarized in Table 8.

The data for each flight pass was extracted from the overall flight file for a given day. The data in Table 5 to Table 8 is based on the azimuth integration for that pass. Typical azimuth integration times are just a few seconds [1]. The aircraft heading and ship course is calculated using the formula below.

$$hdg = \frac{180}{\pi} \times \operatorname{mod}\left\{ \operatorname{atan2}\begin{bmatrix} \sin(lon1 - lon2) \times \cos(lat2), \\ \cos(lat1) \times \sin(lat2) - \sin(lat1) \times \cos(lat2) \times \cos(lon1 - lon2) \end{bmatrix}, 2 \times \pi \right\} \quad (7)$$

where *hdg* is in degrees, *lon1* and *lat1* are the longitude and latitude of the start position in radians, and *lon2* and *lat2* are the longitude and latitude of the end position in radians.

Table 5: Data acquisition and vessel velocity parameters obtained from the NADAS and dGPS.

Line/ Pass	Radar Look	Aircraft		*Quest*				*Grenfell*				*Sambro*				*Divecom III*			
		Hdg (º)	Vel (kts)	θ_{inc} (º)	φ_{asp} (º)	Hdg (º)	V (kts)	θ_{inc} (º)	φ_{asp} (º)	Hdg (º)	V (kts)	θ_{inc} (º)	φ_{asp} (º)	Hdg (º)	V (kts)	θ_{inc} (º)	φ_{asp} (º)	Hdg (º)	V (kts)
l1p3	Left	225.2	121.4	45.5	271.2	314.0	1.4	41.0	123.9	101.3	1.6	52.4	267.7	317.5	1.2				
l2p4	Right	45.3	139.7	43.9	138.3	267.0	4.5	39.6	133.9	271.4	5.6	51.1	134.5	270.8	4.7				
l3p5	Right	225.1	122.0	36.2	135.1	90.0	5.0	44.1	135.7	89.4	5.0	27.1	138.6	86.5	5.1				
l4p6	Right	45.2	141.2	46.5	138.2	267.0	10.3	37.8	150.1	255.1	10.2	51.1	136.8	268.4	9.7				
l5p7	Right	225.1	122.5	34.6	134.1	91.0	10.9	45.7	130.7	94.4	9.6	31.9	142.9	82.2	9.8				
l6p8	Right	360.0	141.8	44.7	91.0	269.0	5.1	42.2	93.7	266.3	3.7	56.8	92.6	267.4	4.4				
l7p9	Right	180.1	127.2	38.6	87.1	93.0	5.4	43.6	86.8	93.3	5.1	51.7	79.0	101.1	5.4				
l8p10	Right	90.0	139.9	47.7	179.0	271.0	12.0	38.4	176.0	274.0	12.9	36.1	180.6	269.4	12.0				
l1p1	Right	90.0	143.2					44.9	56.8	33.2	0.8	35.1	191.6	258.5	1.2	36.1	-36.3	126.3	1.2
l2p2	Left	225.3	142.3					39.9	312.1	273.2	5.3	30.9	318.0	267.3	5.3	47.2	-48.4	273.7	4.9
l3p3	Left	45.1	130.9					39.3	313.5	91.6	4.7	47.5	319.0	86.1	4.6	40.0	-36.9	82.0	4.9
l4p4	Left	225.2	140.8					36.4	318.4	266.8	10.1	28.8	322.1	263.1	9.9	43.4	-46.6	271.8	10.0
l5p5	Left	45.1	133.6					38.3	317.1	88.0	10.0	46.8	313.6	91.5	9.9	29.6	-45.5	90.6	9.4
l6p6	Left	225.1	141.6	37.7	321.1	264.0	5.1												

Table 6: CFAV *Quest* motion and wave information.

Line	Pass	Roll Angle (°)	Roll Rate (°/s)	Pitch Angle (°)	Pitch Rate (°/s)	Yaw Rate (°/s)	Lat Acc (G's)	Long Acc (G's)	Vert Acc (G's)	Wave Height (m)	Avg Wave Period (s)
24-Mar-04 (Part One)											
1	3	Data not available									
2	4	Data not available									
3	5	Data not available									
4	6	-3.14	-0.20	-0.45	-0.04	1.11	0.0030	-0.0564	-0.0026	0.3	7.9
5	7	-4.02	0.15	-0.12	0.01	0.97	0.0016	-0.0769	-0.0029	0.2	7.6
6	8	-3.90	0.18	-0.33	-0.01	0.91	0.0029	-0.0701	-0.0066	0.2	6.5
7	9	-2.54	0.13	-0.38	0.08	0.02	0.0041	-0.0474	-0.0009	0.2	6.9
8	10	-3.31	-0.08	0.00	0.04	0.80	0.0011	-0.0590	-0.0014	0.3	8.5
24-Mar-04 (Part Two)											
6	6	-3.19	0.46	-0.07	0.03	0.23	0.0010	-0.0618	0.0032	1.0	4.9

Table 7: Vessel locations from dGPS data.

ASAR	Line/ Pass	*Quest*		*Grenfell*		*Sambro*		*Divecom III*	
		Lat (N°)	Lon (W°)	Lat (N°)	Lon (W°)	Lat (N°)	Lon (W°)	Lat (N°)	Lon (W°)
301	l1p3	44.285117	63.752367	44.299891	63.748514	44.300096	63.699291		
302	l2p4	44.284408	63.772825	44.299441	63.767083	44.299408	63.720532		
303	l3p5	44.281683	63.757133	44.298690	63.760484	44.300017	63.706426		
304	l4p6	44.278450	63.781983	44.300394	63.782726	44.299082	63.731696		
305	l5p7	44.279050	63.762983	44.298550	63.774179	44.299831	63.726723		
306	l6p8	44.280267	63.768700	44.299372	63.775370	44.300696	63.725827		
307	l7p9	44.281017	63.763550	44.299753	63.775960	44.301662	63.800979		
308	l8p10	44.279217	63.787933	44.296920	63.789466	44.300494	63.833757		
309	l1p1			44.300847	63.750612	44.318347	63.754620	44.316855	63.699889
310	l2p2			44.300959	63.781562	44.317617	63.786305	44.315451	63.732737
311	l3p3			44.298714	63.771794	44.318127	63.776840	44.315872	63.718124
312	l4p4			44.299044	63.812440	44.316644	63.809793	44.314826	63.765546
313	l5p5			44.296953	63.776123	44.318035	63.779128	44.312540	63.727947
314	l6p6	43.902800	63.684483						

Table 8: Information collected during data processing.

Date	Line/Pass		Asar Number	Cal Line Used	Look Direction	Image Reversal	Comments
22-Mar-04	l1p2						
	l2p2	Cal Line	297	298			Missing annotation block
			298		Port		Very difficult to extract VH, VV noise
23-Mar-04	l10p1	Cal Line	299				Bad noise file, image not calibrated
23-Mar-04	l11p2	Cal Line	300				Bad noise file, image not calibrated
23-Mar-04	l1p3		301	317	Port	East-West	azimuth ambiguity
23-Mar-04	l2p4		302	317	Starboard	NO	
23-Mar-04	l3p5		303	318	Starboard	NO	
23-Mar-04	l4p6		304	317	Starboard	NO	Synchronized with Envisat. Stripped in 2 parts, ships are in part A, azimuth ambiguities
23-Mar-04	l5p7		305	318	Starboard	NO	
23-Mar-04	l6p8		306	317	Starboard	NO	
23-Mar-04	l7p9		307	318	Starboard	NO	
23-Mar-04	l8p10		308	317	Starboard	NO	azimuth ambiguity
24-Mar-04	l1p1		309	317	Starboard	NO	stripped in 2 parts, ships are in part A azimuth ambiguities
24-Mar-04	l2p2		310	317	Port	East-West	
24-Mar-04	l3p3		311	318	Port	East-West	azimuth ambiguities
24-Mar-04	l4p4		312	317	Port	East-West	azimuth ambiguities
24-Mar-04	l5p5		313	318	Port	East-West	azimuth ambiguities
24-Mar-04	l6p6		314	317	Port	East-West	azimuth ambiguity
24-Mar-04	l7p7		315				2 parts, no noise, can't process
24-Mar-04	l8p8		316				no noise, can't process
24-Mar-04	l10p9	Cal Line	317		Port	East-West	45°
24-Mar-04	l11p10	Cal Line	318		Starboard	NO	35°

5.2 Calibration Site

Four calibration lines were acquired; however, two of them cannot be processed because there is no internal calibration data (noise data) available. Two successfully acquired and processed calibration lines are l2p2 and l3p3 on March 24. The polarimetric SAR images of the calibration site are shown in Figure 15 and Figure 16. An incidence angle of 45° with the left looking mode characterizes the l2p2 acquisition, and an incidence angle of 35° with the right looking mode characterizes l3p3. It should be noted that the image obtained from l2p2 has East and West reversed from the usual frame of reference due to the left mode acquisition. Four ARCs and four CRs can be clearly identified in the both calibration lines. In l2p2, the calibration devices can be seen from azimuth pixels of about 520 to 1700, while in l3p3, they can be seen from azimuth pixels of about 210 to 130.

The calibration parameters used in the data processing for the ship images are from either one of these two calibration site images, depending on the incidence angle used for the ship image acquisition. Because not all the calibration lines are usable, we are undertaking an analysis of system stability from day to day in an effort to determine the error in using data from one day to calibrate data from a previous or subsequent day. Control data from collections having a complete set of calibration lines will be used to validate this effort.

Target to clutter ratio is studied using HH channel data. A mean TCR of great than 15 dB is obtained from both lines, as indicated in Figure 17 - 20.

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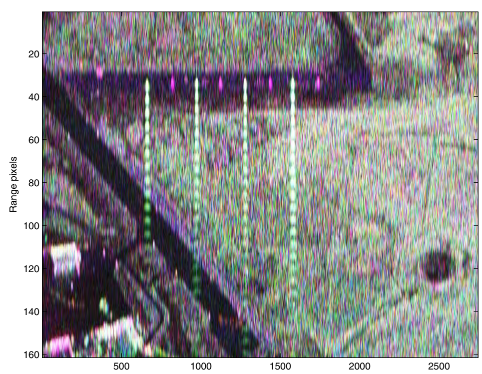

Figure 15: Polarimetric SAR image of the calibration site – Left looking mode (45˚ inc).

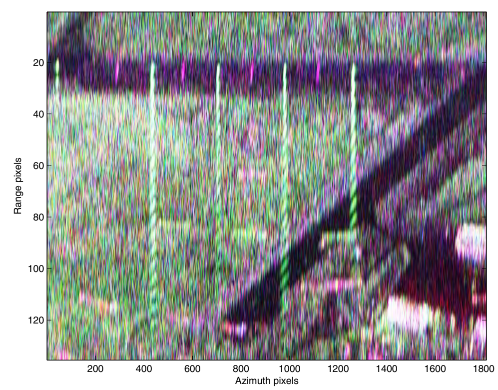

Figure 16: Polarimetric SAR image of the calibration site – Right looking mode (35˚ inc).

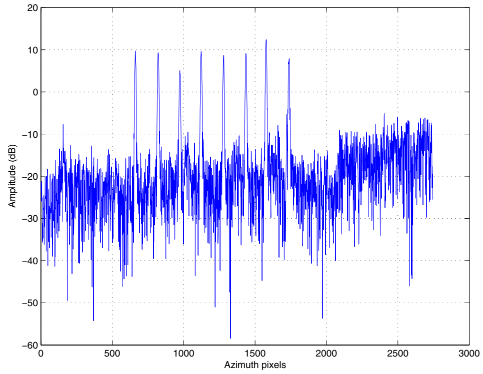

Figure 17: Calibration devices (left looking mode) in the azimuth direction (1 range sample) using HH channel.

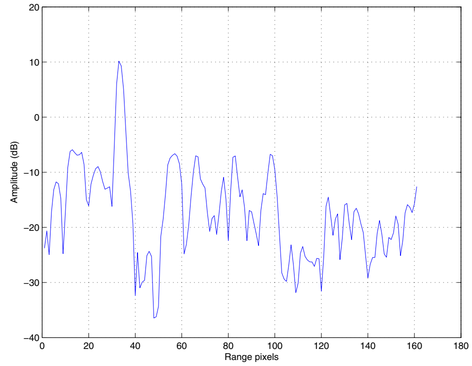

Figure 18: A CR (left looking mode) in the range direction (1 azimuth sample) using HH channel.

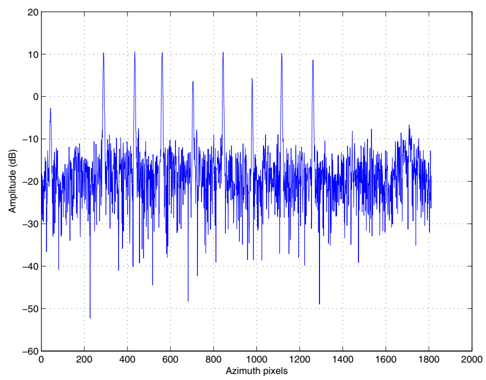

Figure 19: Calibration devices (Right looking mode) in the azimuth direction (1 range sample) using HH channel.

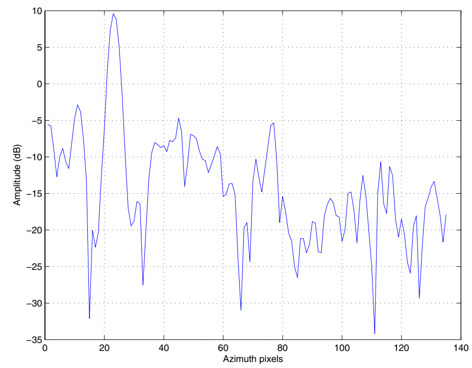

Figure 20: A CR (right looking mode) in the range direction (1 azimuth sample) using HH channel.

5.3 Vessels Imaged

Fourteen ship images were acquired, however, two of them cannot be processed because there is no valid internal calibration data available, subject to application of data from alternate flights All processed images, along with the vessel locations obtained from dGPS data, are presented in Annex F**.**

For one imaging event, simultaneous CV-580 and ENVISAT ASAR data were obtained, namely, l4p6, March 23. ENVISAT was operated in an AP mode (HH/VV) with an incidence angle of 29.73^{o} at the *Quest*. The resolution for this image is 30 m in ground range and 30 m in azimuth with equivalent number of looks (ENL) > 1.8. The incidence angle of the CV-580 was 48º at the center target (CFAV *Quest*). The ships had a velocity of 5.14 m/s (10 kts) towards the sensor with an aspect angle of 45° (i.e. starboard bow was imaged). The images obtained from the both sensors are shown in bottom of Figure 21.

Three ships, CFAV *Quest*, CCGS *Sir Wilfred Grenfell* and CCGC *Sambro,* participated in this portion of the work and are all evident within the CV-580 data (left image). However, only two ships, the *Quest* and the *Grenfell* can be seen within the ENVISAT scene (right image).

The images often appear smeared, and azimuth ambiguities are also observed in some images. A detailed study of these issues and analysis of the trial data are ongoing. We will compare the results from both sensors (CV-580 and ENVISAT).

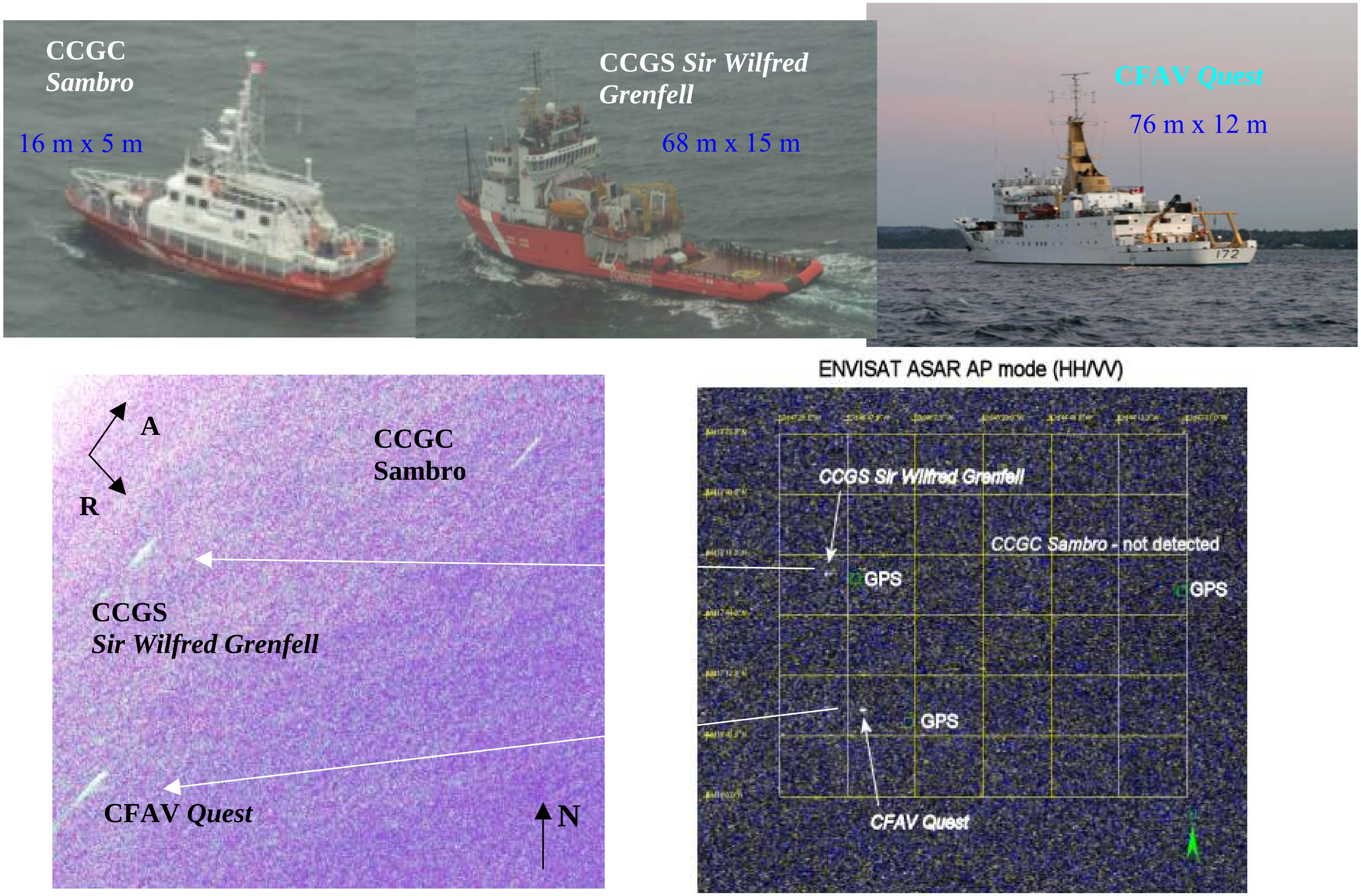

Figure 21: Example of coincident data acquisition of SAR images from both airborne and spaceborne sensors.

6. Summary and Conclusions

A series of imaging radar data collections was acquired during the MarCoPola trial, held March 22-26, 2004 at sea 20 nm SSW of Halifax, Nova Scotia. This collection targeted controlled formations of 2-3 ships operating in tandem, i.e., in close proximity at the same course and speed. Combinations of the CFAV *Quest*, CCGS *Sir Wilfred Grenfell*, CCGC *Sambro*, and the fishing vessel *Divecom III* were employed, with each vessel instrumented with a differential GPS unit to record ship manoeuvring. Targets of opportunity, both vessels and non-vessels, within or approaching the imaging region were tracked and photographed by CP-140 Maritime Patrol Aircraft.

Calibration data for these collects were acquired at a dedicated site located at CFB Shearwater. The instrumentation included four C-band ARCs, four 75 cm trihedral corner reflectors and 2 Ashtech GPS base stations. Due to the location, the calibration data swaths also included the urban surroundings and Halifax Harbour. Four lines of polarimetric SAR imagery and two lines of MTI data were collected of the calibration site.

The data collected at sea is centred on the formations of ships. Seven lines in MTI mode were acquired of the *Grenfell* and *Sambro* in tandem. An ENVISAT overpass coincident with a CV-580 line acquisition of the *Quest*, *Grenfell* and *Sambro* produced near-simultaneous SAR imagery from both airborne and spaceborne sensors. The majority of data collected was polarimetric C-band SAR imagery using the airborne sensor. Fourteen lines, eight of the *Quest*, *Grenfell* and *Sambro* operating in formation, five of the *Grenfell*, *Sambro* and *Divecom III*, and one of the *Quest* alone were acquired. Within this collection of PolSAR data, the incidence angles on each vessel range from 27.1° to 56.8°, while their speed is approximately one of the set {1, 5, 10, 12} given in knots. In each image, all the vessels exhibit geometric imaging aspect angles at or near one of {90°, 135°, 180°, 270°, 315°}.

Normally, algorithms aimed at characterizing maritime targets are developed on data where the target vessels operate independently. Since only a finite set of data is used in the development, there may be variables, called operating conditions, that characterize these data sets but are independent of the target that appears in them, such as geometry, vessel activity, or environmental conditions. This collection has imaged multiple ships with their operating conditions aligned, providing the capability to validate that algorithms, particularly for polarimetric signatures, characterize the differences between ships rather than operating conditions.

7. References

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Annex A. Calculation of Corner Reflector Bore-Sight Angle

The bore-sight angle is computed as detailed below. A sketch of a CR is shown in Figure 22.

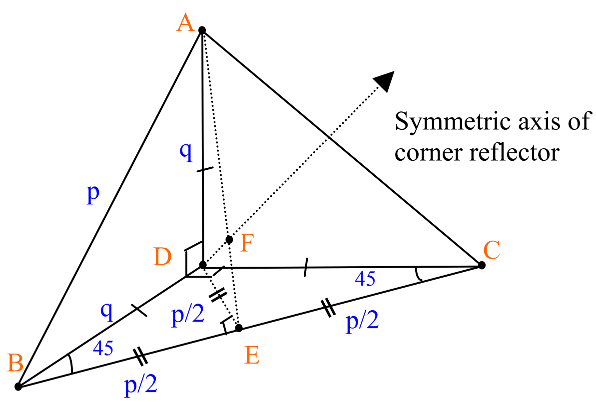


Figure 22: Sketch of a Corner Reflector.

The bore-sight angle (θ_{bore}) is

$$\theta_{bore} = 90° - \alpha,$$

where

$$\alpha = tan^{-1}\left(\frac{q}{p/2}\right) = tan^{-1}\left(\sqrt{2}\right) = 54.74^{o},$$

which yields $\theta_{bore} = 35.26^{\circ}$.

Annex B. Deployment of Corner Reflectors and ARCs

Entries in black are desired values, while those in red are recorded measurements. An "X" indicates desired values achieved.

Table 9: Corner reflector deployment

Line	Direction to Aircraft	Corner Bore Azimuth (MN)	Corner Edge Alignment (Right to Left)	DREA			DREV			DREP			DREO		
				Location (UTM)			**Location (UTM)**			**Location (UTM)**			**Location (UTM)**		
				N 44 38 38.54280			N 44 38 35.70067			N 44 38 32.75059			N 44 38 29.91548		
				W 063 30 39.17557			W 063 30 35.62361			W 063 30 31.90426			W 063 30 28.33777		
				Az.	Corner Elevation (degrees from horizontal)		Az.	Corner Elevation (degrees from horizontal)		Az.	Corner Elevation (degrees from horizontal)		Az.	Corner Elevation (degrees from horizontal)	
Mar 22	NE		**157.4**	-	**9.8**	-	-	**9.8**	-	158	**9.8**	9.8	158	**9.9**	9.8
Mar 23 A	NE		**157.4**	X	**9.8**	9.9	156.5	**9.8**	9.8	X	**9.8**	9.8	X	**9.9**	9.9
Mar 23 B	NE		**157.4**	X	**19.9**	20.1	X	**19.9**	20.1	X	**19.9**	19.8	X	**19.9**	19.5
Mar 24 A	NE		**157.4**	X	**9.8**	9.9	X	**9.8**	9.9	X	**9.8**	9.8	X	**9.9**	9.9
Mar 24 B	NE		**157.4**	X	**19.9**	19.9	X	**19.9**	20	X	**19.9**	19.9	X	**19.9**	20
Mar 26 A	NE		**157.4**	X	**9.8**	9.8	158	**9.8**	9.7	X	**9.8**	9.8	X	**9.9**	9.8
Mar 26 B	NE		**157.4**	*X*	***4.8***	*5.1*	*158*	***4.8***	*5.1*	*X*	***4.8***	*5.1*	*X*	***4.8***	*4.9*

Table 10: ARC deployment.

Line	Direction to Aircraft	Corner Bore Azimuth (MN)	Corner Edge Alignment (Right to Left)	Power Hog (CCRS 1-2542)				Gemini (CCRS 2-2811)				Serafina (CCRS 1-2756)				Noah (DRDC Ottawa)			
				Location (UTM)				**Location (UTM)**				**Location (UTM)**				**Location (UTM)**			
				N 44 38 37.07876				N 44 38 34.27651				N 44 38 31.38169				N 44 38 28.43342			
				W 063 30 37.24303				W 063 30 33.67799				W 063 30 30.08363				W 063 30 26.43004			
				Az	ARC Incidence (degrees from horizontal)			Az	ARC Incidence (degrees from horizontal)			Az	ARC Incidence (degrees from horizontal)			Az.	ARC Incidence (degrees from horizontal)		
						TX	RX			TX	RX			TX	RX			TX	RX
Mar 22	NE		**157.4**	-	**44.9**	-	-	X	**44.9**	44.8	44.9	X	**44.9**	45	45.1	X	**44.9**	45.1	44.7
Mar 23 A	NE		**157.4**	X	**44.9**	44.7	44.5	X	**44.9**	44.7	44.7	158	**44.9**	45.1	45	X	**44.9**	44.5	44.6
Mar 23 B	NE		**157.4**	X	**34.9**	35	35	X	**34.9**	35.1	34.7	X	**34.9**	34.9	35.5	X	**34.9**	34.7	34.7
Mar 24 A	NE		**157.4**	X	**44.9**	45	44.8	X	**44.9**	44.7	44.8	X	**44.9**	45.1	45.1	X	**44.9**	44.7	44.7
Mar 24 B	NE		**157.4**	X	**34.9**	34.8	34.9	X	**34.9**	35	34.8	158	**34.9**	34.8	35.1	X	**34.9**	35	34.7
Mar 26 A	NE		**157.4**	X	**44.9**	44.7	44.7	158	**44.9**	44.6	44.5	X	**44.9**	44.8	45	X	**44.9**	44.9	45
Mar 26 B	NE		**157.4**	*X*	***49.9***	*49.8*	*49.8*	*X*	***49.9***	*49.9*	*49.2*	*X*	***49.9***	*50.3*	*51.6*	*X*	***49.9***	*49.6*	*49.7*

Annex C. Flight Operations and Communication Plans

By Bryan Healey

PART A - Flight Operations

DATE	PLATFORM	TIME (ON-SITE)	PROFILE	ALTITUDE
23 March (23 2000-24 0400Z)	CV 580 (EC) C-GRSC	**2320 Z - 1920 (L)** **2400 Z - 2000 (L)**	Cal Site Lines - HZ 7-50 nm Lines Centered on Position A	220 - 230
	CP 140 Aurora (DND)	**2300 Z - 1900 (L)**	Seek and Identify Targets Within **30 nm** of Position A	300 - 5000
	Research 9 (NRC)	N/A	N/A	N/A
24 March (24 1600-2300Z)	CV 580 (EC) C-GRSC	1830 Z - 1430 (L)	7-50 nm Lines Centered on Position A	FL 220 - 230
	CP 140 Aurora (DND)	1730 Z - 1330 (L)	Seek and Identify Targets Within **30 nm** of Position A	1500 AGL & Above After 1900 Z 1000' & Above
	CV 580 (EC) C-GRSC	2000 Z - 1600 (L) to Quest, after CCG work done	7-50 nm Lines Centered on Position B	FL 220 - 230
	CP 140 Aurora (DND)	2000 Z - 1600 (L) to Quest, after CCG work done	Seek and Identify Targets Within **30 nm** of Position B	1500 AGL & Above After 1900 Z 1000' & Above
	Research 9 (NRC)	1730 Z - 1330 (L) 1900 Z - 1500 (L)	MAG Anomalies Hyperspectral Characteristics	1000' AGL 300' AGL - 500'AGL

NOTES:

1.	23 March	Position A -	44° 18' ; 63° 45'	Main Target
	24 March	Position A	44° 18' ; 63° 45'	Main Target CCG Sambro/Sir Wilfred Grenfell and rented vessel Divecom III
		Position B	43° 54' ; 63° 39'	Main Target Quest

2. EC CV580 (C-GRSC) will be communication focal point for airborne operations directly related to MarCoPola. Frequencies in Part B.
3. Main Target and compliments will only change course and speeds on instruction from CV580 C-GRSC.
4. Ancillary participants are to monitor communication frequencies as per Part B.
5. CP 140 Aurora and Research 9 - CV 580 should use UHF communication for position and altitude conflict as required preventing clutter on main communication frequencies.
6. All changes in flight planning must be co-ordinated through Bryan Healey - EC CV 580 Captain in YHZ - contact provided in Part B.
7. Generally, schedules are marginally flexible plus or minus half to one hour except for satellite under flight 23 March, 22:00 (L) - 0200 Z - 24 March for EC CV 580 - C-GRSC.
8. Contingency will be handled as required - DRDC Part B - Communication - David Schlingmeier.
9. C-GRSC will attempt HF Communication with participants before C-GRSC's departure each day on HF 2510, 30 minutes prior to scheduled departure time. It would be helpful if all participants were monitoring HF 2510 upper S/B 30 minutes prior to scheduled departure for C-GRSC until exercise is called complete.

PART B - Communications

Primary Communications

- 30 Minutes Prior to C-GRSC Departure
  - HF 25,100 upper S/B
- During Operations
  - CV 580's, Quest – Channel 19 – 161.55
  - CP 140, CV 580's – 1223 VHF
  - CV 580's Cal Site - 149.59 FM
  - Research 9, CP 140 - UHF 279.4
- Alternate Communication
  - CP 140, CV 580's - 123.45 VHF, 2237 HF U/SB, UHF - 249.8
  - CV 580's Quest – Channel 18 – 161.5

Secondary Communications

- HF - 2237 U/SB - All participants
- VHF - 126.7 - All participants where applicable.

NOTE: Secondary communication should only be used if directed by C-GRSC.
Emergency Frequencies (all well known) VHF - 121.0, VHF/FM - 156.8, HF – 2182.

Annex D. Crucial Covair Radio Calls to Ships

By Shawn Gong and Pete Beaulne

Mar 23, Tuesday, PolSAR
On Station Time 21:00, <u>Quest</u> as the leading ship

- Lead-in on Line 1
- End of Image on Line 1 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 5 minutes of turning
- Lead-in on Line 2
- End of Image on Line 2 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 5 minutes of turning
- Lead-in on Line 3
- End of Image on Line 3 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 5 minutes of turning
- Lead-in on Line 4
- End of Image on Line 4 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 5 minutes of turning
- Lead-in on Line 5
- End of Image on Line 5 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 7-10 minutes of turning
- Lead-in on Line 6
- End of Image on Line 6 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 5 minutes of turning
- Lead-in on Line 7
- End of Image on Line 7 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 10 minutes of turning
- Lead-in on Line 8
- End of Image on Line 8 (about 10 minutes after Lead-in call)
- **Go home**

Mar 24, Wednesday, PolSAR
On Station Time 14:30, Grenfell as the leading ship

- Lead-in on Line 1
- End of Image on Line 1 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 7-10 minutes of turning
- Lead-in on Line 2
- End of Image on Line 2 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 5 minutes of turning
- Lead-in on Line 3
- End of Image on Line 3 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 5 minutes of turning
- Lead-in on Line 4
- End of Image on Line 4 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 5 minutes of turning
- Lead-in on Line 5
- End of Image on Line 5 (about 10 minutes after Lead-in call)

CCG ships and Divecom III Go home

On Station Time 16:00, Quest

- Lead-in on Line 6
- End of Image on Line 6 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 5 minutes of turning
- Lead-in on Line 7
- End of Image on Line 7 (about 10 minutes after Lead-in call)
- ❖ Waiting: 5 minutes of Lead-out, plus 10 minutes of turning
- Lead-in on Line 8
- End of Image on Line 8 (about 10 minutes after Lead-in call)

Quest Go home

Annex E. Ships Operation during the experiment

The ship operation plan for the experiment is attached in this Annex as a value reference for the future trial planning. The actual operational notes can be found in [13]

By Shawn Gong and Pete Beaulne

Ship ID: CCGS Sir Wilfred Grenfell

It is designed that the ship is operating around its nominal position: 44°18' N 63°45' W during the course of the experiment. There is a possibility that the aircraft flight time is longer in upwind and shorter in tailwind. That means the ship may drift off the nominal position. If possible, such drift should be compensated when the aircraft is turning.

Ship ID: CCGS Sir Wilfred Grenfell

March 23, Tuesday, Flight ID 04-04B
On Station Time 21:00, Quest as the leading ship

Starting position 44°18' N 63°45' W

Line 1:
Starting position 44°18' N 63°45' W
Bearing 270°, Speed 0 kts,

Station keeping only, no movement

Line 2:
Starting position 44°18' N 63°45' W
Bearing 270°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 3:
Starting position: the end of the last run
Bearing 90°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 4:
Starting position: the end of the last run
Bearing 270°, Speed 10 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 5:
Starting position: the end of the last run
Bearing 90°, Speed 10 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 6:
Starting position: the end of the last run
Bearing 270°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 7:
Starting position: the end of the last run
Bearing 90°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 8:
Starting position: the end of the last run
Bearing 270°, Speed 15 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Go home upon receiving "Image end" or "Lead-out" from the aircraft.

Ship ID: CCGS Sir Wilfred Grenfell

March 24, Wednesday, Flight ID 04-04C
On Station Time 14:30, Grenfell as the leading ship

Starting position 44°18' N 63°45’ W

Line 1:
Starting position 44°18' N 63°45’ W
Bearing 270°, Speed 0 kts,

Station keeping only, no movement

Line 2:
Starting position 44°18' N 63°45’ W
Bearing 270°, Speed 5 kts,

Accelerate upon receiving “Lead-in” from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving “Image end” or “Lead-out” from the aircraft.
Come back to the original track, ready for the next run.

Line 3:
Starting position: the end of the last run
Bearing 90°, Speed 5 kts,

Accelerate upon receiving “Lead-in” from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving “Image end” or “Lead-out” from the aircraft.
Come back to the original track, ready for the next run.

Line 4:
Starting position: the end of the last run
Bearing 270°, Speed 10 kts,

Accelerate upon receiving “Lead-in” from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving “Image end” or “Lead-out” from the aircraft.
Come back to the original track, ready for the next run.

Line 5:
Starting position: the end of the last run
Bearing 90°, Speed 10 kts,

Accelerate upon receiving “Lead-in” from the aircraft. Maintain the desired speed
Go home upon receiving “Image end” or “Lead-out” from the aircraft.

<u>Ship ID: CCGC Sambro</u>
It is designed that the ship is operating around its nominal position for each day during the course of the experiment. There is a possibility that the aircraft flight time is longer in upwind and shorter in tailwind. That means the ship may drift off the nominal position. If possible, such drift should be compensated when the aircraft is turning.

Ship ID: CCGC Sambro

March 23, Tuesday, Flight ID 04-04B
On Station Time 21:00, Quest as the leading ship

Starting position 44°18' N 63°42' W **2 nm east of the Grenfell**

Line 1:
Starting position 44°18' N 63°42' W
Bearing 270°, Speed 0 kts,

Station keeping only, no movement

Line 2:
Starting position 44°18' N 63°42' W
Bearing 270°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 3:
Starting position: the end of the last run
Bearing 90°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 4:
Starting position: the end of the last run
Bearing 270°, Speed 10 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 5:
Starting position: the end of the last run
Bearing 90°, Speed 10 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed

Start to turn 180° upon receiving “Image end” or “Lead-out” from the aircraft.
Come back to the original track, ready for the next run.

Line 6:
Starting position: the end of the last run
Bearing 270°, Speed 5 kts,

Accelerate upon receiving “Lead-in” from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving “Image end” or “Lead-out” from the aircraft.
Come back to the original track, ready for the next run.
At the end of Run 6, keep moving to the west until it is 2 nm west of the Grenfell.
Probable position 44°18’N 63°50’ W.

Line 7:
Starting position: the end of the last run
Bearing 90°, Speed 5 kts,

Accelerate upon receiving “Lead-in” from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving “Image end” or “Lead-out” from the aircraft.
Come back to the original track, ready for the next run.

Line 8:
Starting position: the end of the last run
Bearing 270°, Speed 15 kts,

Accelerate upon receiving “Lead-in” from the aircraft. Maintain the desired speed
Go home upon receiving “Image end” or “Lead-out” from the aircraft.

Ship ID: CCGC Sambro

March 24, Wednesday, Flight ID 04-04C
On Station Time 14:30, Grenfell as the leading ship

Starting position 44°19' N 63°45' W
Two smaller ships should follow each other, distance between two ships is 2 nm

Line 1:
Starting position 44°19' N 63°45' W
Bearing 270°, Speed 0 kts,

Station keeping only, no movement

Line 2:
Starting position 44°19' N 63°45' W
Bearing 270°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 3:
Starting position: the end of the last run
Bearing 90°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 4:
Starting position: the end of the last run
Bearing 270°, Speed 10 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 5:
Starting position: the end of the last run
Bearing 90°, Speed 10 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Go home upon receiving "Image end" or "Lead-out" from the aircraft.

<u>Ship ID: Quest</u>

It is designed that the ship is operating around its nominal position for each day during the course of the experiment. There is a possibility that the aircraft flight time is longer in upwind and shorter in tailwind. That means the ship may drift off the nominal position. If possible, such drift should be compensated when the aircraft is turning.

March 23, Tuesday, Flight ID 04-04B
On Station Time 21:00, Quest as the leading ship

Starting position 44°17' N 63°45' W

Line 1:
Starting position 44°17' N 63°45' W
Bearing 270°, Speed 0 kts,

Station keeping only, no movement

Line 2:
Starting position 44°17' N 63°45' W
Bearing 270°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 3:
Starting position: the end of the last run
Bearing 90°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 4:
Starting position: the end of the last run
Bearing 270°, Speed 10 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 5:
Starting position: the end of the last run
Bearing 90°, Speed 10 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 6:
Starting position: the end of the last run
Bearing 270°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 7:
Starting position: the end of the last run
Bearing 90°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

Line 8:
Starting position: the end of the last run
Bearing 270°, Speed 15 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Go home upon receiving "Image end" or "Lead-out" from the aircraft.

Ship ID: Quest

March 24, Wednesday, Flight ID 04-04C
On Station Time 16:00, Quest only

Line **6**:
Starting position 43°54' N 63°39' W
Bearing 270°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

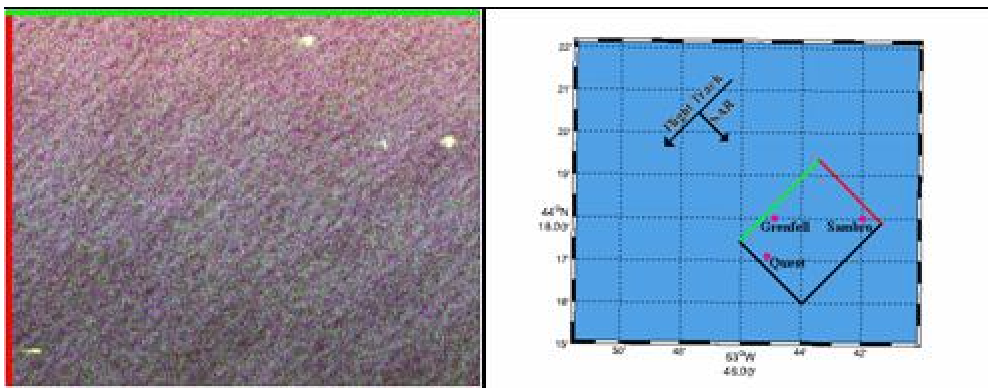
Line **7**:
Starting position: the end of the last run
Bearing 90°, Speed 5 kts,

Accelerate upon receiving "Lead-in" from the aircraft. Maintain the desired speed
Start to turn 180° upon receiving "Image end" or "Lead-out" from the aircraft.
Come back to the original track, ready for the next run.

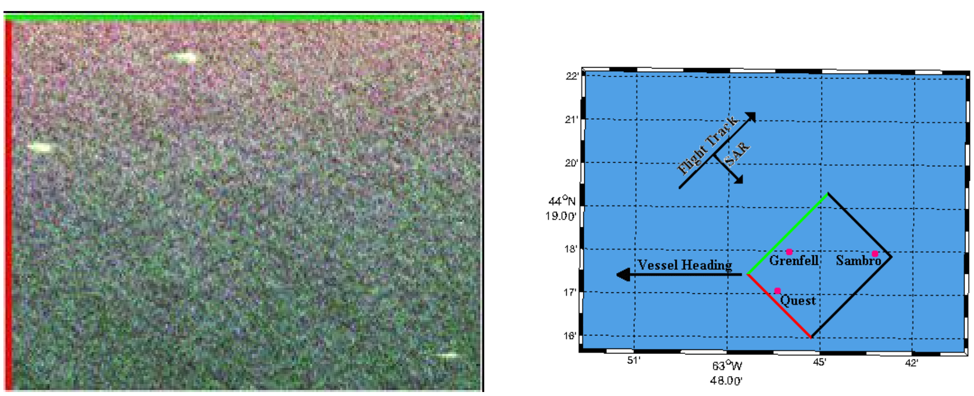
Line **8**:
Starting position: the end of the last run
Bearing 270°, Speed 10 kts,

Annex F. Initial Image Results and Target Location Map

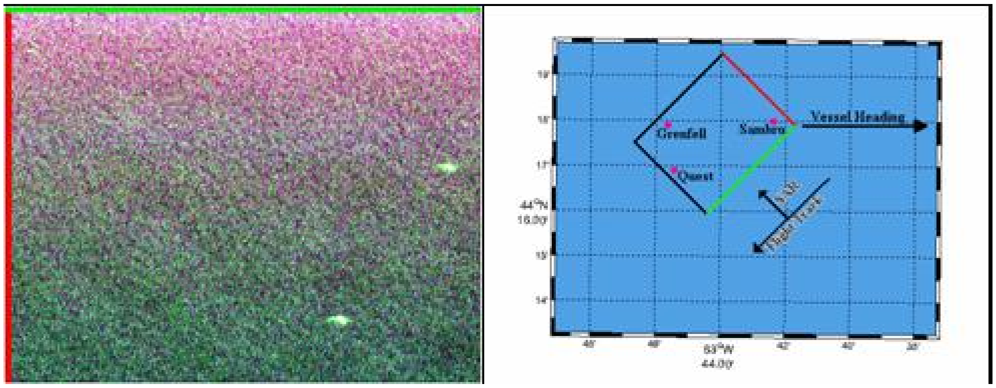
The images obtained from the trial are presented in this Annex. The x axis of the images presents azimuth pixels and the y axis presents range pixels. The aircraft heading and vessel course are obtained from dGPS data and indicated in an actual map orientation, the vertical scale is latitude and the horizontal scale is longitude [12].



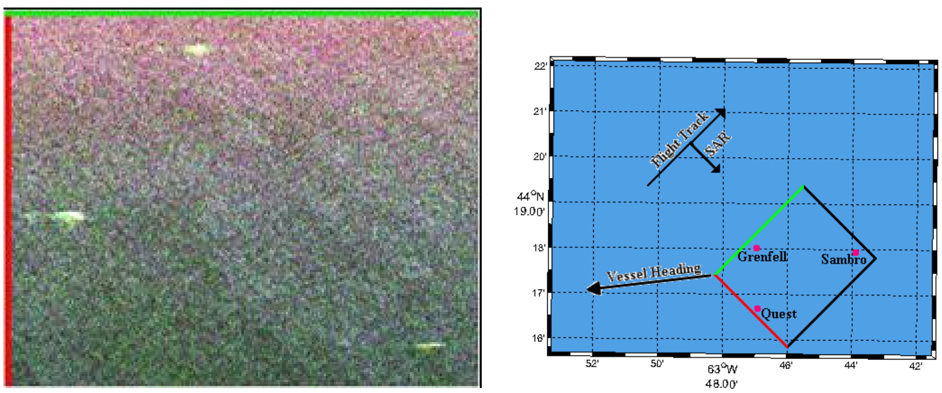
a) l1p3. (vessels are static)



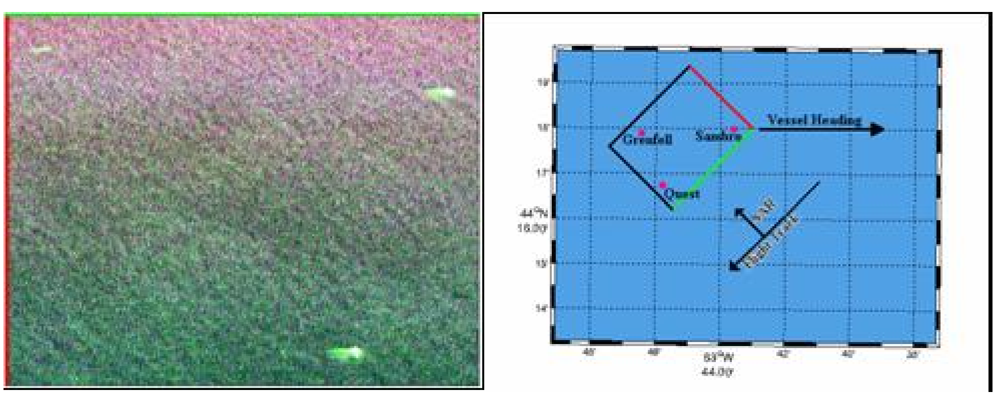
b) l2p4.



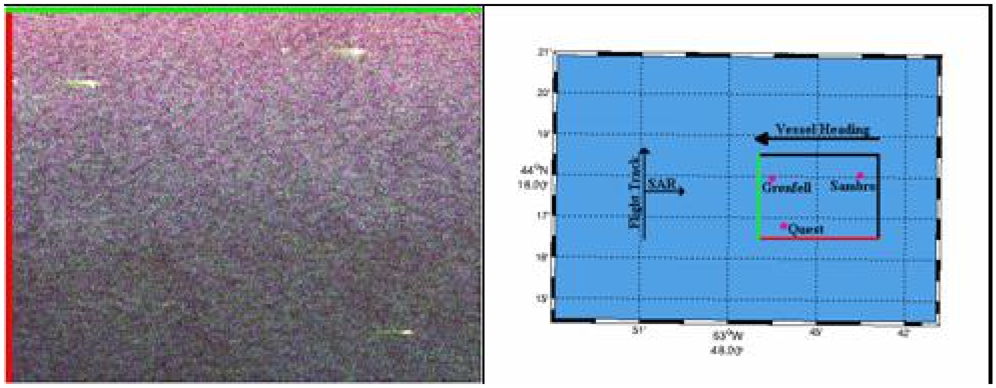
c) l3p5.



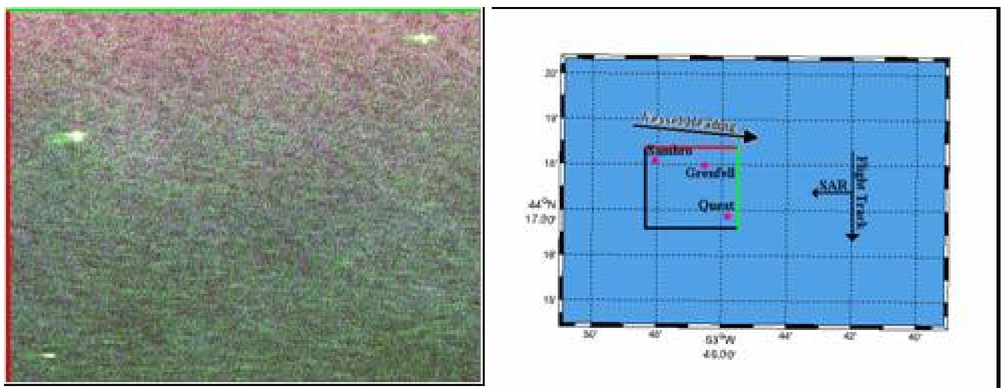
d) l4p6.



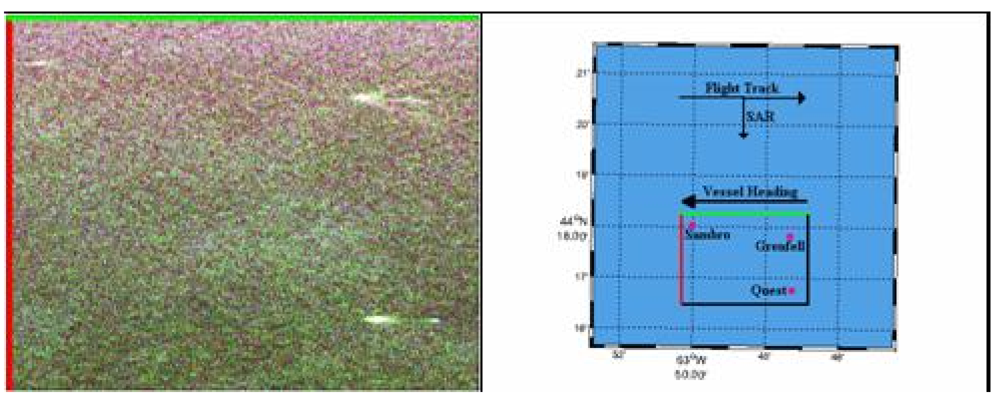
e) l5p7.



f) l6p8.

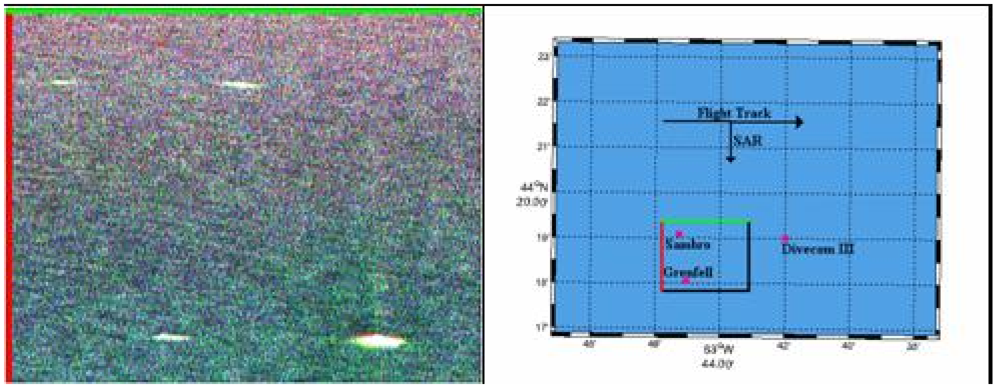


g) l7p9.

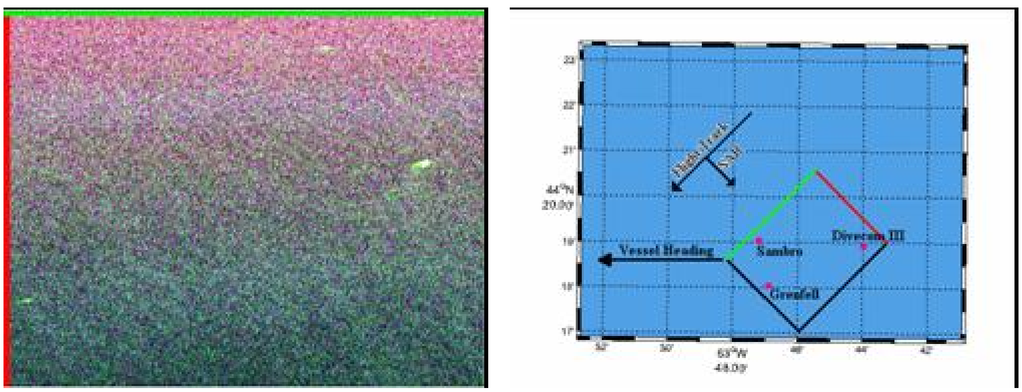


h) l8p10.

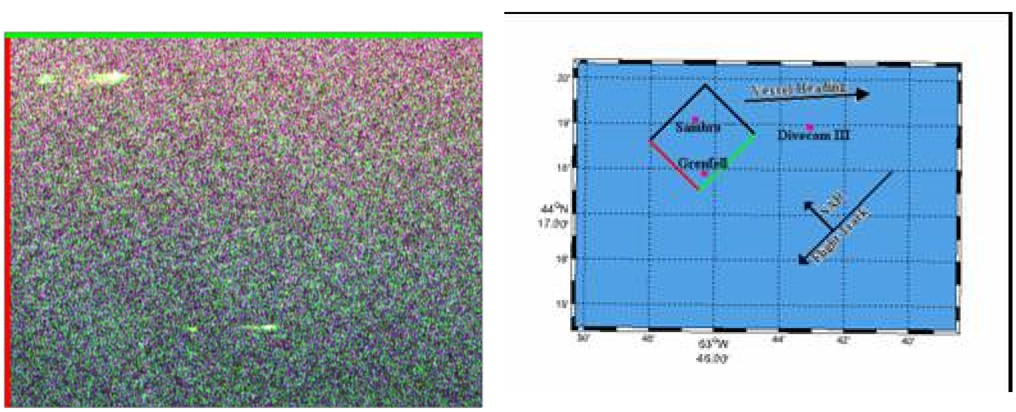
Figure 23: Polarimetric images of vessels, aircraft flight track and vessel locations on 23 March 2004. Near range (green) and first range line (red) of images indicate collection orientation.



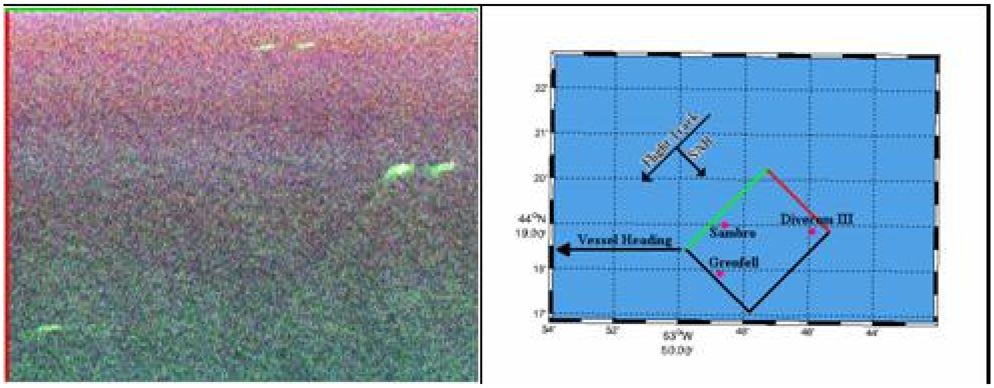
a) l1p1. (vessels are in stationary position)



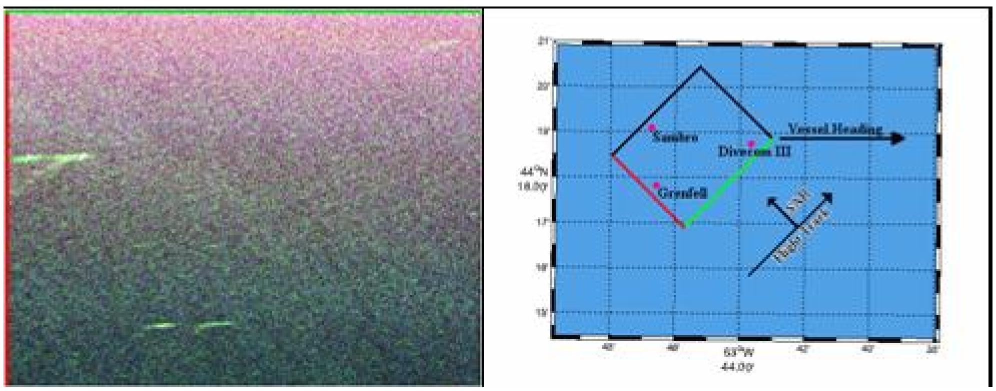
b) l2p2.



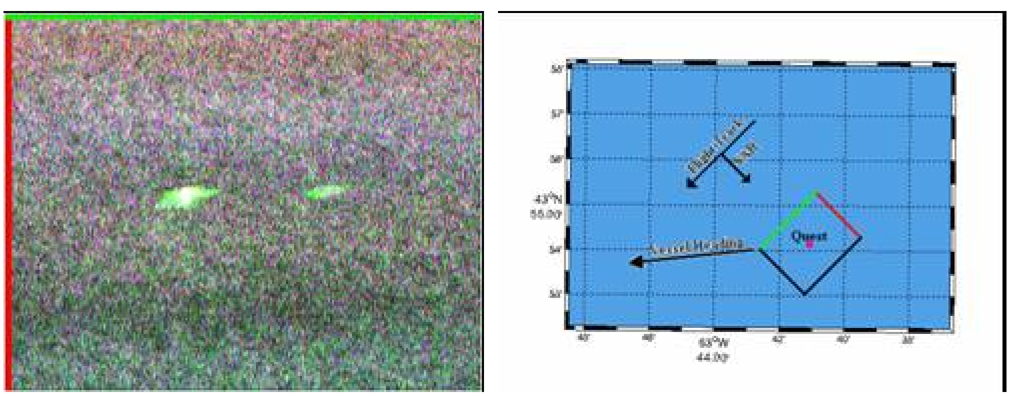
c) l3p3.



d) l4p4.



e) l5p5.



f) l6p6.

Figure 24: Polarimetric images of vessels, aircraft flight track and vessel locations on 24 March 2004. Near range (green) and first range line (red) of images indicate collection orientation.

List of symbols/abbreviations/acronyms/initialisms

ARC	Active Radar Calibrator
AZ	Azimuth
CAD	Canadian Air Division
CCG	Canadian Coast Guard
CCGC	CCG Cutter
CCGS	CCG Ship
CCRS	Canada Centre for Remote Sensing
CFAV	Canadian Forces Auxiliary Vessel
CFB	Canadian Forces Base
CoG	Course over Ground
CR	Corner Reflector
CSA	Canadian Space Agency
CSI	Commercial Satellite Imagery
CV-580	Convair 580
dGPS	Differential Global Positioning System
DIAC	
DND	Department of National Defence
DRDC	Defence Research and Development Canada
EC	Environment Canada
ENL	Equivalent number of looks
EOADP	Earth Observation Application Development Program
FM	Frequency Modulation
GMTI	Ground Moving Target Indicator

GPS	Global Positioning System
HF	High Frequency
ISR	Intelligence, Surveillance and Reconnaissance
MAC	Maritime Air Command
MarCoPola	Maritime Cooperative Polarimetric
MMTI	Maritime Moving Target Indicator
MN	Magnetic North
MPA	Maritime Patrol Aircraft
MTI	Moving Target Indicator
NADAS	Non-acoustic Data Acquisition System
NRC	National Research Council
P_{FA}	Probability of False Alarm
PolSAR	Polarimetric SAR
RCS	Radar Cross Section
RGD	Range Gate Delay
SAR	Synthetic Aperture Radar
SAW	Surface Acoustic Wave expander
SAW^{-1}	Surface Acoustic Wave compressor
SoG	Speed over Ground
TACNAV	
TCR	Target to Clutter Ratio
UHF	Ultra High Frequency
VHF	Very High Frequency

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(U) This memorandum addresses design, experimentation, and data collection components of the MarCoPola Polarimetric Signature trial that was conducted off the coast of Halifax, Nova Scotia, March 22-26, 2004 in conjunction with the CFAV Quest trial Q-281. Four ships participated as maritime targets in the experiments: Quest, CCGS Sir Wilfred Grenfell and CCGC Sambro, and Divecom III. C-band Synthetic Aperture Radar imagery of these targets was collected using the sensor on Environment Canada’s CV-580 platform, with a supporting ENVISAT acquisition.

(U) A radar calibration site was established at CFB Shearwater, which offered an adequately high TCR environment. The calibration site was composed of four ARCs, four corner reflectors and two GPS base stations. Additional ground truthing of targets of opportunity were acquired by a CP-140 through contact tracking and photographs.

(U) Fourteen lines of airborne Polarimetric SAR images were successfully collected with the target vessels exhibiting various speeds, incidence angles, aspect angles, and environmental conditions. One line was collected coincident with the ENVISAT acquisition. Four PolSAR lines were collected containing the Shearwater calibration site, also containing urban environments of the greater Halifax area. Seven lines of MTI data were obtained containing the target vessels, and two lines in MTI mode were collected for calibration.

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Polarimetric Syntheture Aperature Radar (PolSAR), Ploarimetric signature